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THE STORY OF THE FRANKLIN INSTITUTE.

BY

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1. FOUNDATION AND EARLY ACTIVITIES.

The casual visitor to the Fels Planetarium, to the great Museum of The Franklin Institute, or to Franklin Hall which will soon be dedicated to the memory of Benjamin Franklin, has little knowledge of the real influence and significance of the old society in whose custody they stand. The frequent inquiries received indicate that the display enjoyed by the visitor has whetted his appetite for information on the subject. This brief resumé of a hundred and thirteen years has been prepared not only for his information, but to honor the foresight, generosity and devotion to the community of those who founded, supported, or directed the many activities of The Franklin Institute during its long life. When it is realized that in the two years from October 1934 to October 1936 the membership of The Franklin Institute increased from fifteen hundred to six thousand, it may be well imagined that it is timely to review the past activities of an organization that has taken such a sudden hold upon the interest of so many people.

FOUNDATION.

Let us travel backward in our minds to December 1823. James Monroe was President of the United States. The

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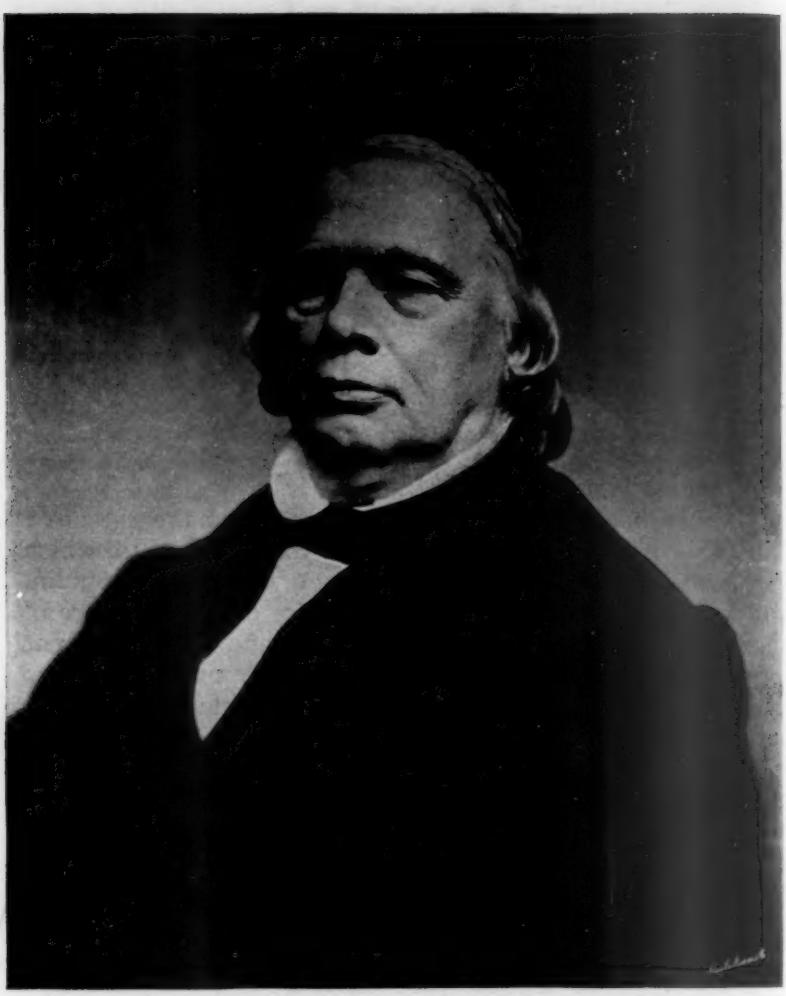


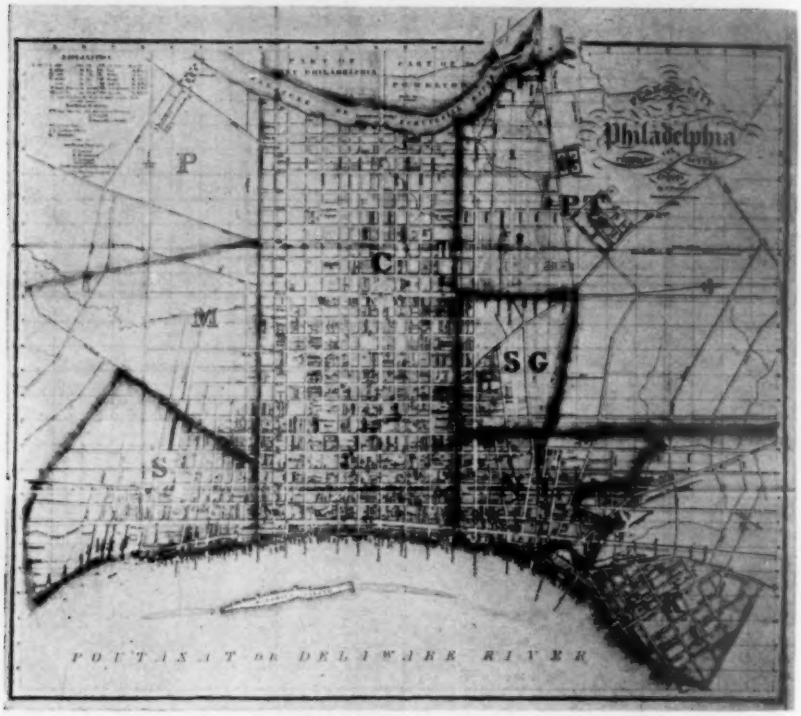
SAMUEL VAUGHAN MERRICK, 1801–1870.

The leading spirit among the founders of The Franklin Institute. He served as its first Treasurer and was its President from 1842 to 1854. He established the Southwark Iron Foundry in South Philadelphia and was instrumental in the introduction of illuminating gas into Philadelphia.

VIEWS OF PHILADELPHIA IN 1799.

Although these drawings were published 25 years before The Franklin Institute was founded, many of the buildings shown were still standing in 1824 and the character of the city had not greatly altered.

last census had shown that the city of Philadelphia had a population of about 64,000, while that of the entire county of Philadelphia was 137,000. The industrial revolution was under way. Machinery was taking the place of hand labor, but few of the social adjustments necessary to that change had commenced. Industry was quickening, although execu-



PHILADELPHIA IN 1824.

This map, prepared the same year that the Institute was founded, was taken from "Philadelphia in 1824," a guide book published by Carey and Lea.

tives and mechanics alike had little technical training and frequently little education. There was no high school in Philadelphia. The crying need of the time was for education, particularly in the sciences.

One of those feeling this need was a young man twenty-two years of age, Samuel Vaughan Merrick. Born in Maine, he had lived in Philadelphia for a number of years, when he was

given by his uncle, Samuel Vaughan, an opportunity to enter a small manufacturing business. Eager to acquit himself with credit, he determined to obtain the proper training. To

WILLIAM HYPOLITUS KEATING, 1799–1840.

A founder of the Institute, its first lecturer and a member of the Board of Managers. From a miniature by Mr. Hugh Bridport, who was the first instructor in freehand drawing in the Institute's school.

his distress he discovered that there was no place in which mechanical training could be obtained by the public. Being young and unafraid he determined to correct this deficiency.

"I called a meeting at the Philosophical Hall of some fifteen or twenty gentlemen who I supposed would take an interest in so useful a movement. The night of the meeting came, and no one responded to the call. After talking the matter over the next day with several who professed an interest in the project, I called a second meeting with a similar result."

Still undismayed, he then allied himself with William H. Keating, a young professor of chemistry at the University of Pennsylvania. Together they obtained the interest and support of a group of about a dozen citizens, mostly young men and only a few of them well to do. A meeting of this group was held on December 9, 1823, in the hall of the American Philosophical Society. It was decided at that meeting to form a society for the promotion of the mechanic arts. A committee was formed to prepare a constitution and another group selected from the Directory twelve to fifteen hundred names of persons whose occupations indicated that they would be likely to favor the movement It is evident that no social barriers were considered but that the persons selected to be notified of the next meeting were drawn from all trades and activities and included artisans as well as manufacturers.

When the meeting for organization was held on the evening of February 5th, 1824, the old County Court House at Sixth and Chestnut was filled to overflowing. The purposes of the proposed Society were explained and unanimously approved. It was resolved that the best mode of obtaining the desired objects would be by the establishment of popular lectures, by the formation of a cabinet of models and minerals, and a library, and by offering premiums on all useful improvements in the mechanic arts. Then the projected constitution was presented, its provisions discussed and amended, and finally adopted, and a day for the election of officers was set. Between four and five hundred persons enrolled as members, and on March 3, 1824, The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts received its charter from the Legislature.

Among the original small group active in the organization of the Institute were others who were distinguished as able

and useful citizens. One was Matthias W. Baldwin, founder of the Baldwin Locomotive Works, who earlier had made tools for calico printers and for bookbinders. Another was Colonel Peter A. Browne, an attorney, who delivered the address at the laying of the cornerstone of the Institute and who was active in the introduction of gas into Philadelphia. James Ronaldson, the first President of the Institute, a leader

THE COUNTY COURT HOUSE.

Where the plans for the formation of The Franklin Institute were approved at a meeting held February 5, 1824. In the background, on the other side of the State House, may be seen the home of the American Philosophical Society where some of the preliminary meetings were held.

in the cotton textile industry, a type founder and philanthropist, was a third.

Other names not mentioned elsewhere in this article that appear as officers, members of the Board or on important committees in the first few years are, Alexander Dallas Bache, Clement C. Biddle, Moses Brown, Matthew Carey, Thomas Fletcher, George Fox, Frederick Fraley, Thomas Gilpin, Dr.

Robert E. Griffith, Frederick Graff, Reuben Haines, John Harrison, Thomas Loud, Thomas McEuen, Lloyd Mifflin, Sheldon Potter, Adam Ramage, James Rush, Thomas Scattergood and Samuel R. Wood.

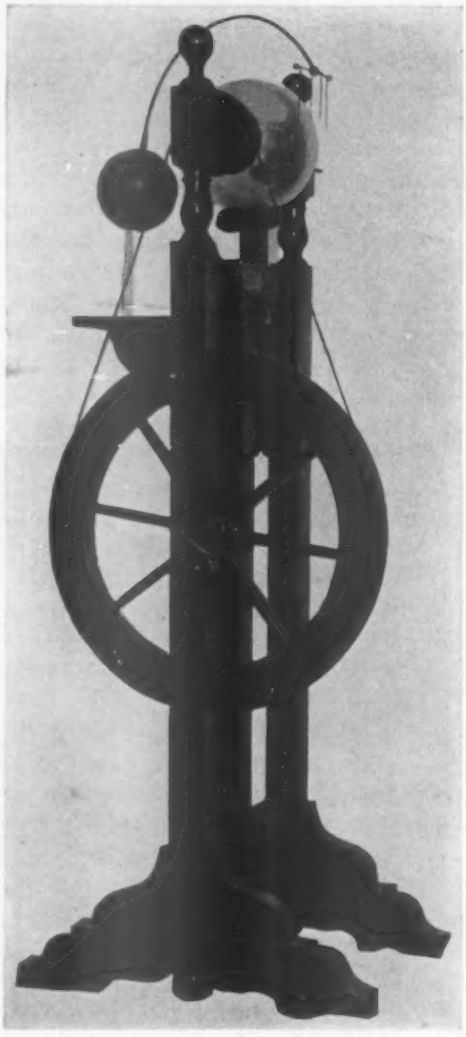
All of the above were active and influential members of the community, and enough of the names will be familiar to anyone interested in the early development of Philadelphia industry, to give a conception of the high position that the Institute immediately took in the minds of leading citizens.

Membership in the Institute was freely open to all interested persons, regardless of station, as the varied occupations of the members testify. The first twenty-one names in the first alphabetical list of members showed thirteen occupations in the following order: Fire-Engine maker, Merchant, Brewer, Teacher, Saddler, Plasterer, Plumber, Marble Mason, Clothier, Shot Manufacturer, Druggist, Counsellor, and Blacksmith. The amazing manner in which The Franklin Institute took a position of leadership during the years of its infancy, can best be explained by its readiness to be of service to the entire community. Not only did it serve the public by its own activities, but it stood ready to lend its aid to many projects originating with others.

The records which remain do not reveal any definite statement as to why The Franklin Institute should have been named in honor of Benjamin Franklin. However, not only are the activities of the Institute devoted to the fields of science in which Franklin was interested, but the purpose of the Institute, the education of young people in technology and the dissemination of knowledge among the mass of people, were dear to Franklin as is shown by his will. It may be surmised that if the founders selected any single characteristic of Benjamin Franklin's personality for honor, it was his *usefulness*. That quality has been consistently preserved throughout the history of the Institute.

EARLY ACTIVITIES.

No time was lost in commencing the various activities of the new society, and within a brief time The Franklin Institute had established its value to the community.



BENJAMIN FRANKLIN'S ELECTRICAL MACHINE.

This famous machine was used by Franklin in his experiments on electricity 1747–1753. It was presented to the Institute in October 1826 by Mr. J. Redman Coxe. From measurements of this machine a number of replicas have been made.

Schools and Lectures.

Dr. William H. Keating was named professor of minerology and chemistry and delivered his first lecture in April 1824, in the old Academy building on Fourth Street near Arch, belonging to the University of Pennsylvania. This was the beginning of the series of lectures on pure and applied science which are still being delivered before the Institute.

In October of the same year a school of architectural and mechanical drawing was organized for members' sons and apprentices. Less than two years later a high school was organized. Known as the Franklin High School, it provided a greatly needed opportunity for education. Within a short time, classes were held in the evening as well as the day time. The curriculum included such subjects as Geography, History, Latin, Greek, French, Spanish, and German as well as the theoretical and practical sciences. The records show that over three hundred scholars were enrolled in 1827.

It was the model upon which was patterned the Central High School, later established by the city as part of the public school system. As the more liberal studies were thus provided for, the Institute was enabled to confine itself more strictly to scientific activities, and many courses were dropped, but the School of Mechanical Drawing continued under its auspices for 99 years.

The lectures have been continued since the foundation. At first they were of a character calculated to be particularly useful to the students. Soon they became reports on the progress of science and technology in this and other countries. For many years these reports have, for the most part, been presented by those actually responsible for the progress or closely affiliated with it. In that manner the Institute members have been in touch with the latest advances in the useful arts and the sciences bearing thereon. A record of these lectures constitutes a survey of the development and advances made in science during the century of amazing progress in which the Institute has made its history.

The Journal.

As scientific publications were expensive and hard to obtain, it was felt that the publication of a Journal would be

useful to industry, to the members and to students in the school of the Institute, as well as to students and apprentices of other cities, who were unable to take advantage of the educational facilities provided by the Institute. The prospectus, issued August 1, 1825, announced the fact that "shortly will be published—

THE
FRANKLIN JOURNAL
AND
MECHANICS MAGAZINE

Under the Patronage of

The Franklin Institute of the State of Pennsylvania, for the Promotion of the Mechanic Arts, Edited by Dr. Thomas P. Jones, Professor of Mechanics in the Institute."

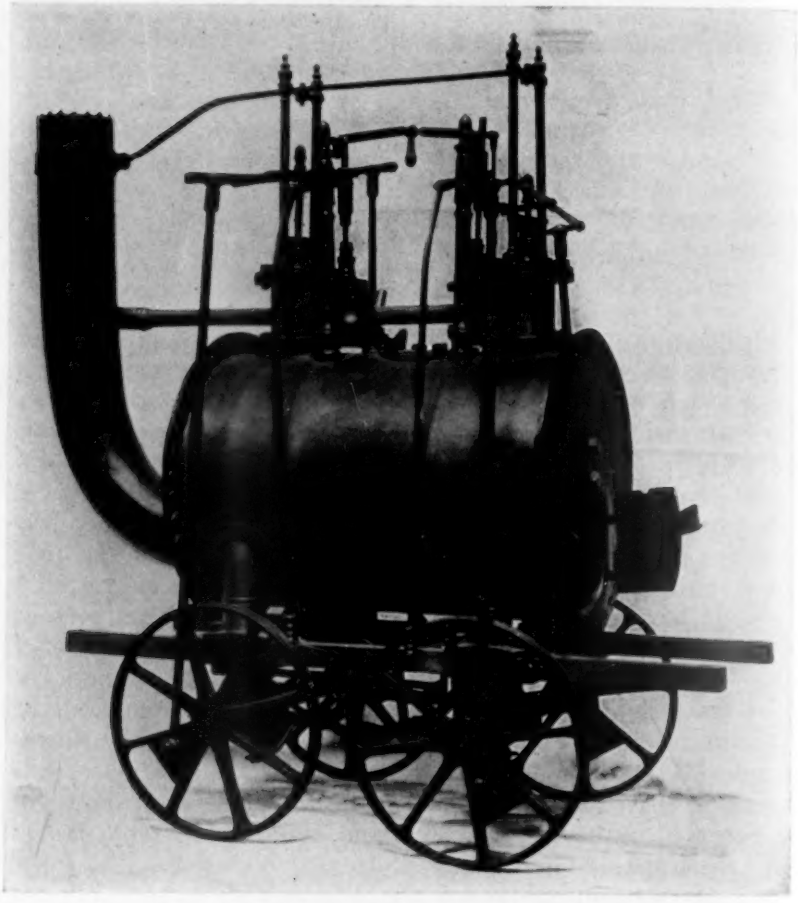
The object of THE FRANKLIN JOURNAL, as defined in the prospectus, was, "to diffuse information on every subject connected with the useful arts." Many of the early articles were translations or abstracts of significant articles published elsewhere. The JOURNAL soon gained a character of its own and the publication of original work became its principal feature, but the critical consideration of other work has always been a part of its policy. Starting in 1828 the title was changed to "THE JOURNAL OF THE FRANKLIN INSTITUTE" and it has been published under that name to the present time.

Dr. Jones was especially interested in patents, and the JOURNAL published an abstract of the specifications and the claims in full. Prior to 1843 the publication of the claims was omitted from the official Patent Office publications, thus making the JOURNAL the only source at present available for reference to the specifications and claims of patents issued by the United States from 1828 to 1842 inclusive. Dr. Jones became Superintendent of the Patent Office, but did not relinquish his connection with the JOURNAL until his death in 1848.

Library.

The plan of the founders for "the formation of a library of books relating to science and the useful arts and the opening of a reading room" received attention in 1827 when the first

Committee on Library was appointed. At first the books were stored in the residence of a member of the committee, but in 1829 the reading room was opened.



MODEL OF STEPHENSON'S LOCOMOTIVE.

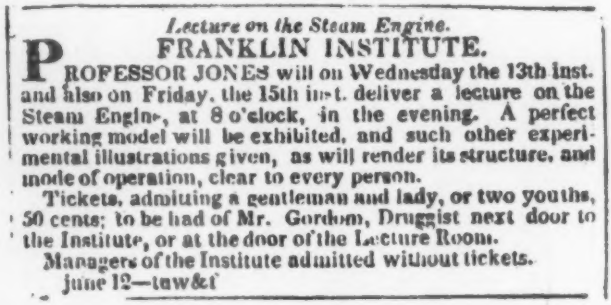
This model of the "No. 1" locomotive built for the Stockton and Darlington Railroad, was made in England and was brought to this country in 1825 by William Strickland, an architect and the Recording Secretary of the Institute. It is displayed in the Hall of Railroad Engineering.

The growth of the library was stimulated by the publication of the JOURNAL, for the subject matter of the JOURNAL was of such importance that exchange relations were easily

established with other societies and with the leading magazines and periodicals devoted to science and the useful arts. These exchanges formed the nucleus of the new library and are still an important factor in the annual increase of the Library.

Committee on Inventions.

A problem that was, apparently, uppermost in the minds of the founders, was the need felt by inventors and discoverers, for some competent, trustworthy and impartial body, on whom they could confidently rely for an opinion as to the usefulness of their inventions and discoveries.



Lecture on the Steam Engine.

FRANKLIN INSTITUTE.

PROFESSOR JONES will on Wednesday the 13th inst. and also on Friday, the 15th inst. deliver a lecture on the Steam Engine, at 8 o'clock, in the evening. A perfect working model will be exhibited, and such other experimental illustrations given, as will render its structure, and mode of operation, clear to every person.

Tickets, admiting a gentleman and lady, or two youths, 50 cents; to be had of Mr. Gordon, Druggist next door to the Institute, or at the door of the Lecture Room.

Managers of the Institute admitted without tickets.

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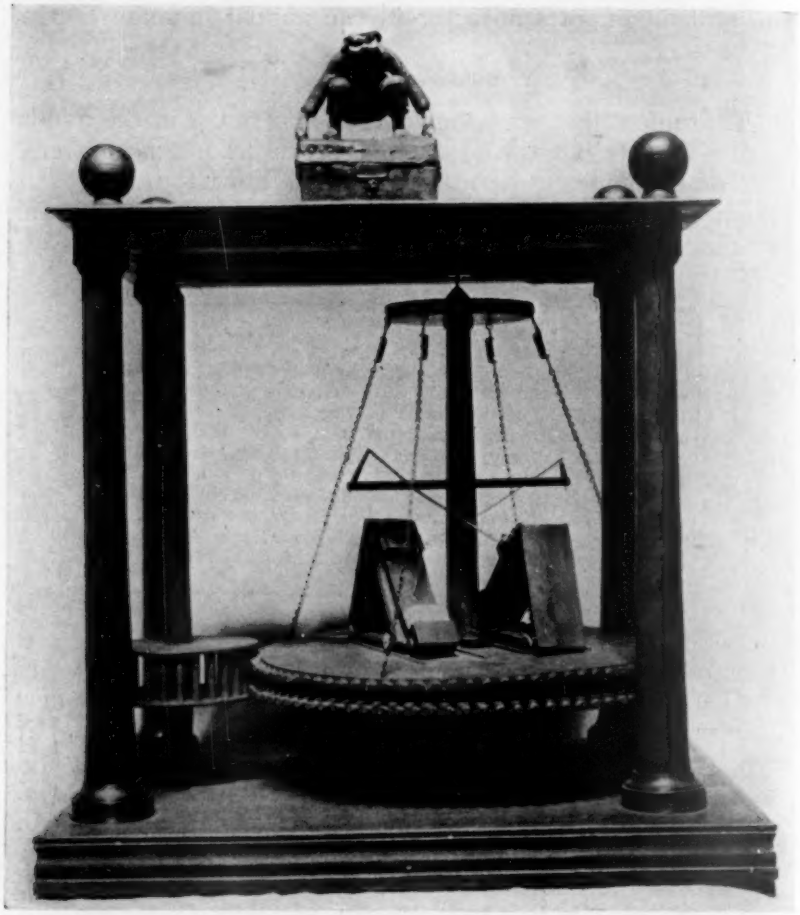
ANNOUNCEMENT OF A LECTURE ON STEAM ENGINES.

One of the first acts of the Board of Managers of the new society was to appoint a Board of Examiners, whose duty it was to examine and make report upon all new and useful machines, inventions and discoveries submitted to them. From its original establishment, such a group has been in continual existence, although its title has been changed. For a brief time it was called "The Committee on Inventions" and since 1834 it has been known as "The Committee on Science and the Arts."

In its earliest years the group gave wise counsel to inventors, pointed out what had previously been accomplished, saved them loss by showing them when their inventions were not new; and when any matter of real novelty or value was presented, endorsed it with their approval and aided in securing public recognition and reward. The scope of the

Committee's activity has been expanded from time to time, and during the last eighty years it has been devoted to an



MODEL OF CHARLES READHEFER'S PERPETUAL MOTION MACHINE.

This model was made in 1812 by Isaiah Lukens who was elected Vice President of The Franklin Institute at its first meeting for the election of officers. It was constructed to expose the fraud in the original machine which was investigated at the request of the State Senate of Pennsylvania. The model was formerly owned by Titian Peale.

increasing degree to the selection of the winners of the various medals and honors in the custody of the Institute.

During the period from June 1825 to December 1833, one

hundred and one cases for investigation were considered. These cover a wide range of subjects and show the beginning of many devices that have been developed further to meet present day requirements and many that applied to activities no longer of importance in our industrial life.

FRANKLIN'S TABLE FOR DRESSING TYPE.

Brought from France when Franklin and his grandson returned to Philadelphia in 1785 and used in the type foundry, established by Franklin for his grandson, Benjamin Franklin Bache. It was presented to the Institute many years ago by members of the Bache family.

Exhibitions.

The first quarterly report of the Board of Managers to the members of the newly formed Institute was presented at a meeting on April 15, 1824. In this report, the importance of public exhibitions, to which all the products of national industry might be sent, was described as follows:

"It is confidently believed that when the products of our industry are collected from the various workshops now dispersed through the city and state, and exhibited together, they will form a collection calculated to excite a gratifying sense of pride . . . and an encouraging hope that under proper regulations, we may soon compete with foreigners in the manufacture of all useful articles."

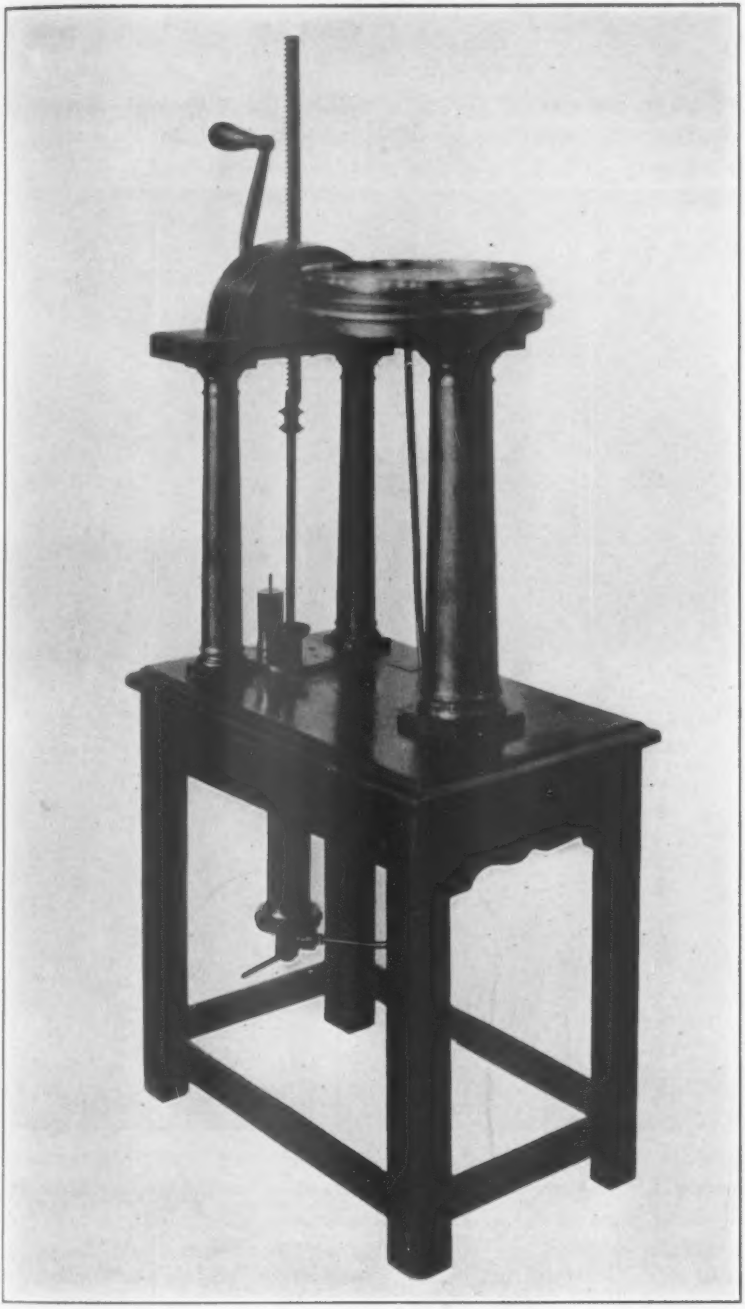
Thus in October of that year, there was held, in Carpenters' Hall, under the auspices of the Institute, the first exhibition of

DR. HARE'S LIGHTNING ROD.

Original Point and Section of Rod made by Dr. Robert Hare for the protection of his mansion at Ninth and Chestnut Streets. Dr. Hare was a member of the Institute and served on the special committee formed for the investigation of steam boiler explosions.

the products of American industry. These displays were continued by the Institute annually or biennially until 1858, and occasionally thereafter. By that time industry had developed to such an extent that specialized exhibitions managed by industrial groups became the custom. The influence of the Institute on this development was considerable and the enthusiasm of the original Board for these exhibitions has been amply justified.

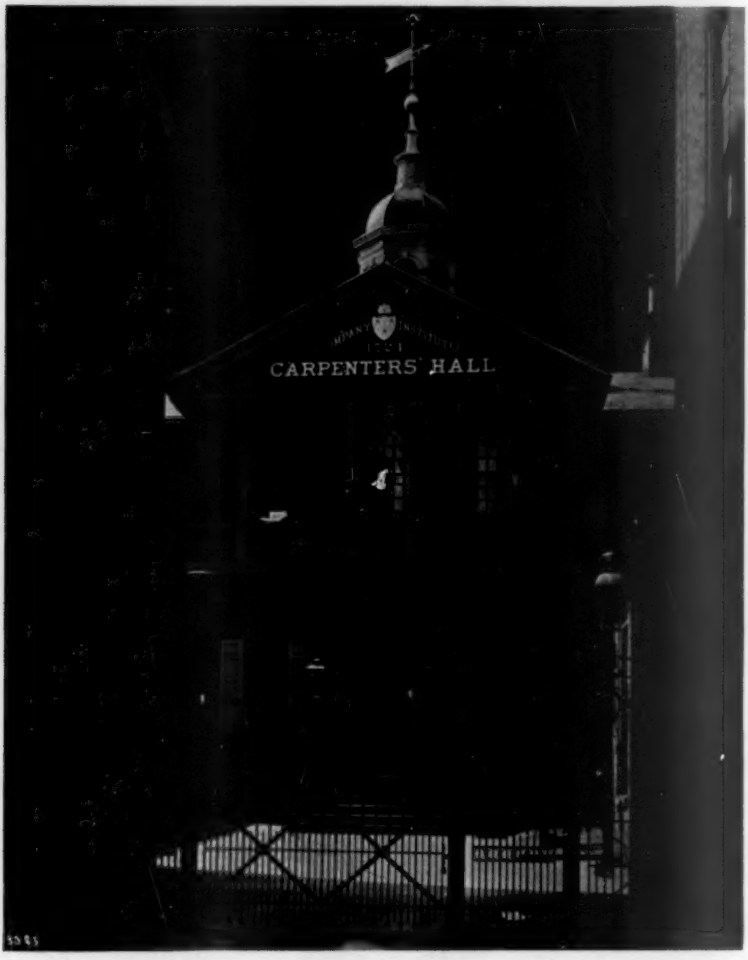
Little time was available between April and October for extensive planning and preparation, but committees were



THE PRIESTLEY AIR PUMP.

This pump was once the property of Dr. Joseph Priestley, one of the discoverers of oxygen and an active investigator of the properties of gases and of respiration. It was presented to the Institute by members of the Sellers family.

formed to pass upon the products of the different classes of industry. Robert Hare, John Harrison, and John P. Wetherill



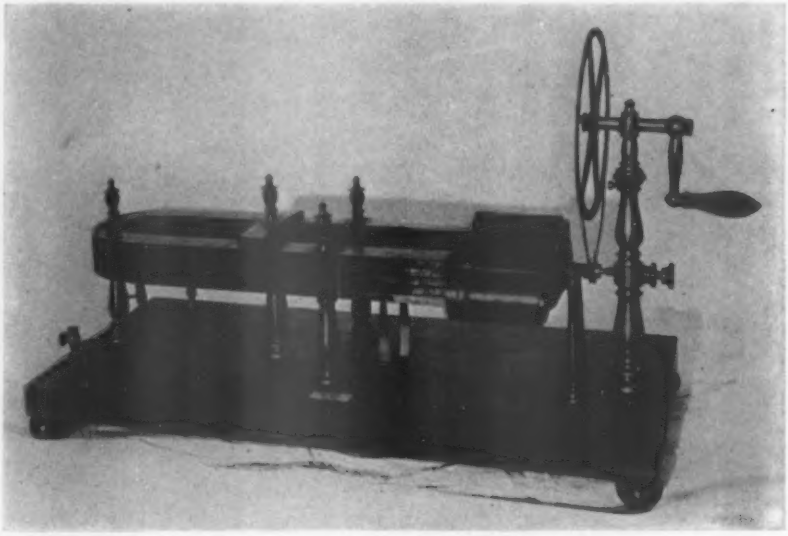
CARPENTERS' HALL.

Where in October 1824, the first exhibition of the products of American Industry was held under the auspices of The Franklin Institute. The lower floor of this building was rented by the Institute until its own building was completed in the following year.

composed the committee on chemicals, and Thomas Sully, William Strickland and Rembrandt Peale served as the com-

mittee on fine arts. Sully also served on the committee on paints and colors. Fifteen other committees were formed, and their comments contained in the official reports on the various exhibits, throw an interesting light on the state of industry at the time.

Awards of silver or bronze medals or of honorable mention were made for blister steel, bar iron, japanned goods, broadcloths, satinettes, cabinet ware, straw and grass bonnets,

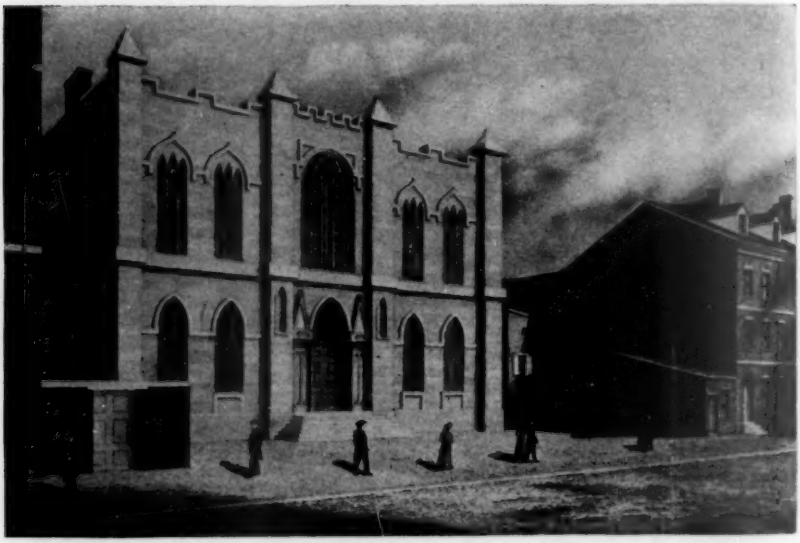


JOSEPH SAXTON'S ELECTRO-MAGNETIC MACHINE.

Saxton was a skilled mechanician and inventor. He was introduced to the Royal Institution by Michael Faraday, and showed a machine similar to this before the British Association for the Advancement of Science in 1833. He became constructor and curator of the United States Mint and was a member of the Board of Managers of The Franklin Institute.

domestic carpeting and so forth. A bronze medal was awarded "to George Catlin, for a bassoon exhibited by him which had many improvements not before introduced in this instrument and the tone and finish of which are excellent." Particular notice was made of busts of General LaFayette by William Rush and by Luigi Persico. A silver medal was awarded to Joseph Saxton for a Clock, "Its 'scapement is upon an entirely new principle and it has a new kind of compensating pendulum." Many specimens of cotton and linen goods

were shown from sources as far away as Rhode Island and Maine. Two pairs of stockings were "made of cotton grown on Bartram's Garden." Woolen goods were entered from Massachusetts, Maryland, and Ohio and several examples by V. & C. Dupont & Co. of Wilmington. Among the books, Carey and Lea showed a Bible, Barton's Flora and Lavoisne's American Atlas. Wilson's Ornithology was entered by Samuel F. Bradford. Agricultural implements were repre-

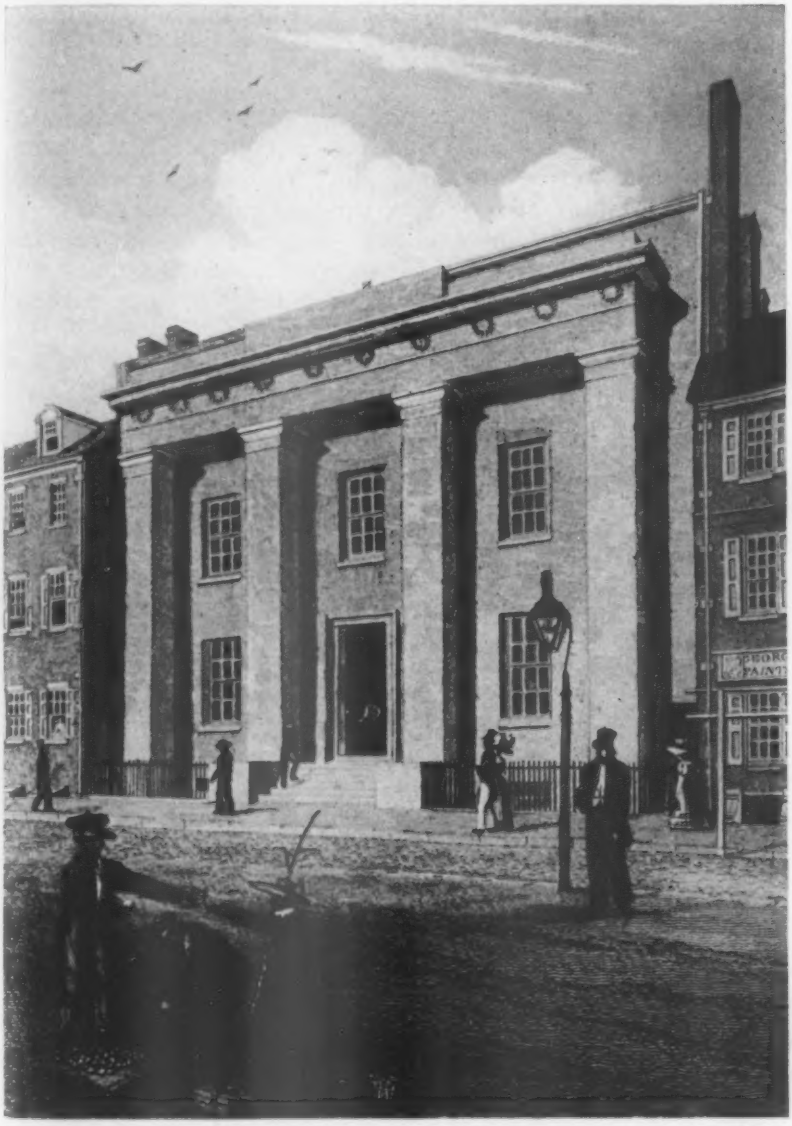


THE MASONIC TEMPLE.

Where the Exhibitions of The Franklin Institute were held from 1825 to 1840. This building stood on the north side of Chestnut Street, between Seventh and Eighth Streets.

sented by a self-sharpening plough by C. and O. Evans "capable of being converted into a never-dulling plough, by substituting a share of a new construction. Another exhibit was "machine paper of J. and T. Gilpin twelve feet long, capable of being made any length, of good materials and well made. . . ."

Much was learned from the first exhibition, and those held in subsequent years brought forth a keen competition for honors among American manufacturers. The awards and comments of the judges are too lengthy for even brief mention



THE FRANKLIN INSTITUTE ON SEVENTH STREET.

Erected in 1825, this old building was the scene of many memorable occasions during the 108 years that it served as the home of the Institute. It still stands on Seventh Street, between Market and Chestnut.

but they are available in the Library of the Institute for those interested.

Headquarters.

As has been mentioned, the first course of lectures was delivered in the Academy Building on Fourth Street. Soon the Institute rented the lower story of the old Carpenters' Hall on Chestnut Street where the first exhibition had been held. As the usefulness of the Institute became rapidly evident, it was shortly decided to erect a building, and a lot on Seventh Street between Market and Chestnut Streets was purchased.

The cornerstone was laid on June eighth, 1825, with appropriate ceremonies and the work carried out according to plans and estimates furnished by John Haviland, the architect, a member of the Board. This was the home of the Institute until its removal to the present site. The last meeting held in the old lecture hall took place on November twenty-third, 1933.

The second story of the building was arranged so that it might be occupied as a courtroom and offices for the Circuit and District Courts. A lease was made with the United States for a term of ten years, but after a short occupancy, the lease was cancelled. The reason for the cancellation is amusing and reflects a picture of the size of the city. It was found inconvenient for members of the bar to be so far from the county courthouse at Sixth and Chestnut.

Special Investigations.

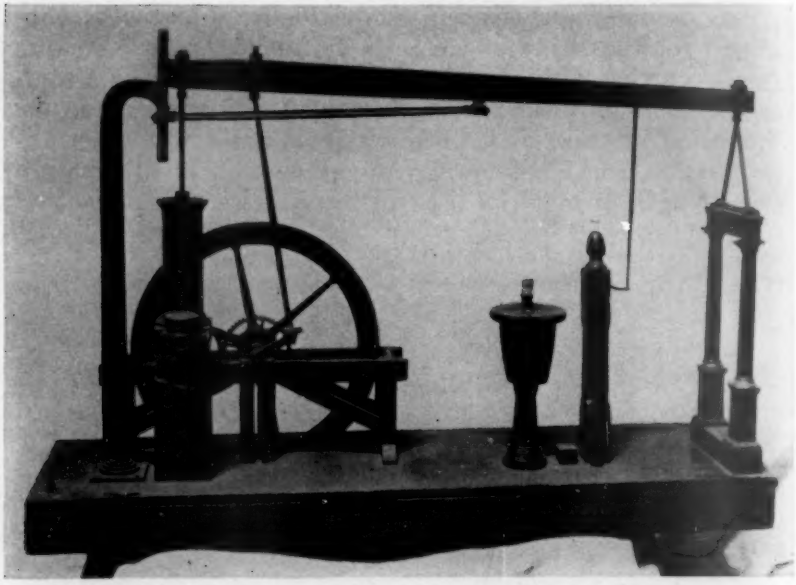
On many occasions the Institute has undertaken intensive studies of problems that were a matter of concern at the time. These investigations were initiated either by the Institute itself or at the request of the local, state or federal government.

The first investigation of this kind was on the subject of water as a source of power. Almost every type of water motor known at the time was investigated, some seven hundred experiments were performed on various types of water wheels, and the results, which were published in the JOURNAL, were of great value to engineers. The expenses of these experiments were met by friends of the Institute, who wished to further the progress of industry.

In the following year, 1830, the Institute formed a committee for the study of steam boiler explosions which were then occurring with alarming frequency especially on steamboats. The government of the United States soon became interested in these experiments and with the aid of an appropriation from Congress, investigations were continued into the strength of material used in the construction of boilers.

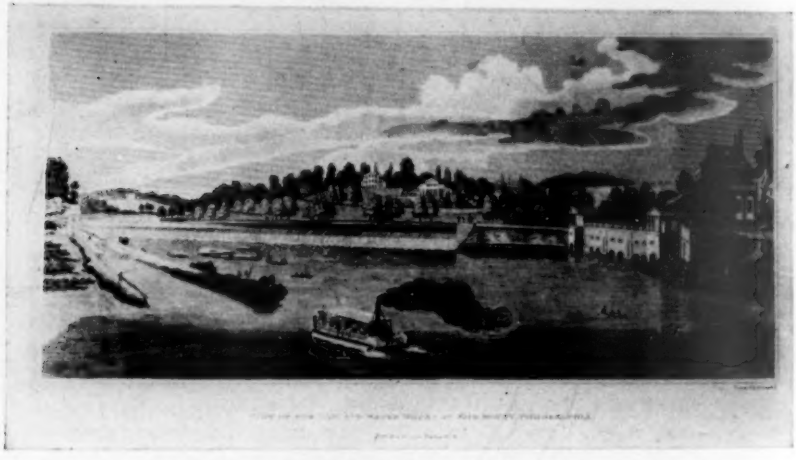
This building, erected in 1800 and demolished in 1825, stood on the site now occupied by the City Hall.

The Congressional appropriation defrayed the actual cost of the experiments, but no part of the money so appropriated was used as compensation for the experimenters. These were all volunteers who devoted months of time to the investigation and discovered valuable facts which have since been utilized for the benefit and safety of the public. The results of these investigations were also published in the



MODEL OF THE OLIVER EVANS HIGH PRESSURE STEAM ENGINE.

The original engine, of which this is a model, was erected at the Fairmount Water Works. Water power was later substituted for steam power. Oliver Evans, an early member of the Institute, was noted for his improvements in the methods of milling and handling grain, and for the "Amphibolous Oruktor" which was probably the first vehicle propelled by steam power in this country. A model of this dredge, constructed by Greville Bathe and Richard Williams, is on exhibition in the Section of Marine Transportation.



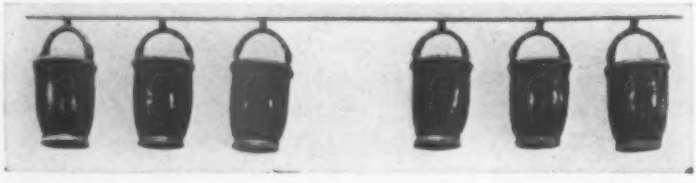
THE DAM AND WATERWORKS AT FAIRMOUNT IN 1824.

It was here that Oliver Evans' steam engine was erected.

JOURNAL, forming a contribution of the utmost value to manufacturers, architects, and builders. They were widely quoted abroad and for many years were regarded as the most authoritative source of information on the subjects to which they related.

An account of The Franklin Institute during the first five or six years of its existence, reveals a rather astonishing record. It is infrequent that a new organization is able to establish itself so rapidly as one of the most useful and most active groups in the community. Credit for this is due not only to the founders who saw the need and sought to meet it, but to the manufacturers and other public spirited citizens who gave to the young society their whole-hearted support and encouragement. It is a comforting characteristic of American life that organizations devoted to public education and the encouragement of industry, can rely upon the continued interest and support of private citizens.

The Franklin Institute continued its career of active service fulfilling the promise of its early youth. The story is lengthy but will be presented in as much detail as space will allow. It is natural that the first few years in the life of a society should contain more than their proportionate share of new services and innovations. This is perhaps less true of The Franklin Institute than of others, for the Institute throughout its existence has shown a willingness not only to pioneer, but to relinquish any activity that appeared to have outlived its usefulness or that was adequately provided for elsewhere.



Ship-to-Shore Radio Telephone.—The Atlantic Communication Corp., a subsidiary of the Atlantic Refining Co., maintains a marine radio telephone system to enable the refining company or other subscribers to direct from their home office buildings in Philadelphia the operations of their tugs plying on the Delaware and Schuylkill Rivers. It is operated in conjunction with the Bell Telephone Co. of Pennsylvania. The shore equipment consists of two unattended radio receivers which pick up the calls from the tugs, an unattended radio transmitter which transmits calls to the tugs, and an attended control terminal. One of the radio receivers is at Girard Point; the other at Point Breeze. The transmitter is on the roof of the company's home office building. All of the shore equipment is connected by wire telephone circuits with the toll switchboard of the Bell company. The control terminal, which unlike the receivers and transmitters requires the constant presence of a skilled operator, has two chief functions. The first is to effect a satisfactory connection between the radio circuits and the wire circuit to the telephone switchboard. The second is to attain the best possible ratio of useful signal to noise which is inevitably introduced by radio transmission. A highly ingenious voice-operated switching device, known as a vodas, enables the terminal to perform its first function. The device permits transmission of speech through the terminal in either direction, but prevents simultaneous transmission in both directions. To switch direction it is only necessary for the speaker to pause. The transmitter is a high frequency, crystal-controlled, 50-watt radio transmitter operated by remote power control over the telephone circuit, and by voice control over the carrier. The carrier can be adjusted to any frequency from 30 to 60 megacycles. The radio receivers are of the a.-c. operated, crystal-controlled superheterodyne type.

R. H. O.

BEARING VALUES OF SOILS.

BY

FRANK N. KNEAS, C.E.,

Member, The Franklin Institute; Amer. Soc. of C.E.

When monumental work is being planned or special conditions are encountered, the architect or engineer, before selecting a bearing value, may order a load test. He may do so although beset with doubts as to its real value and its true interpretation because the usual test which records only the direct settlement of a unit load gives but little information.

In this paper is presented a scale of soil compressibilities, studies of soil structure, findings as to the distribution of stress into soil, and interpretations of tests on fundamentally different types of soil. It separates the elastic from the inelastic settlement and examines the proportionate amounts of stress at different depths under the load. Tentative conclusions are submitted based on the results of the tests. The drop-penetration test, devised by the writer for estimating the comparative bearing values of soils, is described.

The tests are from actual practice and, after erection, the structures erected on several different types of soils were checked for settlement.

SOIL COMPRESSIBILITIES.

To determine compressibilities, samples of natural soil were generally taken with sharpened, smooth steel tubes and put into a testing machine while confined in the tubes. Pressure applied by a piston at each end gave the best results. Observations were also made, through minute glass windows in the sides of the tubes, of movements along the lengths of the soil columns. Samples were also encased in cylinders of sheet celluloid and the stretch of the celluloid was measured to evaluate the lateral pressures. Pauses were made to allow the grains of the finer soils to come to rest after each increase of load.

The compressibilities given, unless otherwise noted, are total compressibilities for the soils in their natural state. They are for the initial loads. Under heavier loads, the grains were crowded together into more compact formations, reducing the compressibilities.

The compressibilities are given in terms of the shortening of a soil column one foot high, under a compression of one ton per sq. ft. After computing the lateral pressure and friction, each compressibility has been corrected to that of a soil ideally restrained, by a frictionless tube, from lateral bulging. This condition is equivalent to that of one of an infinite number of soil columns under load, side by side, the lateral pressures balancing one another. The phenomenon of lateral movement from under a load into surrounding, unloaded soil is examined separately.

No. 1. Two-inch pebbles, artificially arranged in a column	.002" to .004"
No. 2. Very compact sand and gravel, weakly cemented by clay and iron oxide	.008" to .018"
No. 3. Sand and gravel, artificially placed and lightly tamped	.018" to .024"
No. 4. Fine natural sandy soil	.082"
No. 5. Very fine natural sandy soil, not very compact	.140" to .200"
No. 6. Compact, slightly moist, sandy clay	.150"
No. 7. Plastic, black, silty clay	.310"
No. 8. Soft, "greasy," decomposed, mica gneiss	.273" to .400"

The wide range of the compressibilities of natural soils is very noticeable; in this group, No. 8 is thirty times as compressible as No. 2.

As the natural structure of a soil is broken down, the compressibility sometimes increases for a short period but later, as the grains are forced into closer contact, the compressibility decreases; therefore, the unit compressibilities lie on a reverse curve.

The resistance to compression seems to depend almost entirely on the compactness of the formation and very little on the strengths of the individual grains, as shown by the following tests.

STRENGTHS AND ELASTICITIES OF SOIL GRAINS.

Pebbles taken from a stratum of natural gravel which had an "allowable bearing value" of five tons per square foot,

were tested for compressive strengths. The areas of contact between the plates of the testing-machine and the top and bottom of each pebble were measured, as well as the cross-sectional area of each pebble.

Contact pressures varied from 95 tons to 2,232 tons per sq. ft. The crushing values, based on the cross-sectional areas, varied from 19 tons to 714 tons per sq. ft., the average being 280 tons per sq. ft.

Individual grains of sand, measured under the microscope, were also tested. The average crushing value was 224 tons per sq. ft.

The elastic compressibility of quartzose pebbles placed in a single line or column was found to be equivalent to .002″ to .004″ per ton per sq. ft. for a "soil column" one foot high. The square foot of "soil column" may be assumed to be made up of 2″ spherical pebbles, arranged in six rows in each direction, one foot high, thus forming a cubic foot of pebbles restrained from lateral buckling, but without friction on the enclosing sides. The average compressibility, of .003″ per foot of length per ton of load, corresponds to a modulus of elasticity in compression of 4,000 tons per sq. ft., which is about one-twelfth of that of average "solid rock," having a bearing value of about 25 tons per sq. ft., and one-one-hundredth of that of average building stone.

STRUCTURE AND COMPACTNESS OF SOILS.

The structure of a soil is governed largely by the sizes of its grains which may be approximately classified, as follows:

Boulders and cobbles	down to	1½″	diameter
Pebbles	1½″	to 1/4″	diameter
Gravel	1/4″	to 1/16″	diameter
Sand—coarse to fine	1/16″	to 1/500″	diameter
Silt	1/500″	to 1/5,000″	diameter
Clay	1/5,000″	to 1/2,000,000″	diameter

Since grains of clay are smaller than 1/3,000″ across they cannot be seen by the naked eye; the finest grains, say 1/2,000,000″ across, cannot be seen clearly enough to be examined even with high-powered microscopes, but can only be observed under the ultra-microscope, and observers differ as to their shape and structure.

Compactness, which is the main factor in the soil's resistance to compression, depends largely on the conditions under which the soil was laid down.

Beds of coarse sands and gravels which in their formation were laid down, and tamped by pebbles and cobbles rolled over them by swift waters, are found to be more compact than either silts, deposited by slowly moving currents, or clays, which have gradually settled from suspension.

In many cases, superposed strata have compacted underlying ones, and such lower strata have remained compacted even though later erosion has removed the superposed strata.

Long ages are required for any soil to reach its maximum degree of consolidation. The movements of individual grains, particularly of small grains, throughout the mass of any soil, are exceedingly slow.

Superposed loads, at first, compact only the upper layers. Readjustments of the underlying grains in the underlying beds may continue for centuries. Natural soils, of any but the most recent formations, have reached a stable condition.

All natural soils have a structure that is the result of the grains having been in contact for long ages during which the voids have been at least partially filled with finer particles, and the edges of contact have been cemented, even though very weakly, by colloidal silica, or by compounds of magnesia, lime, iron, or other elements.

Recent fill, on the other hand, continues to settle for scores of years, even under its own weight. Any foundation placed on such fill at no matter how light a pressure will also settle. In fact, fill sometimes settles away from under the foundation which it was supposed to support, the foundation being held in place by local cantilever or arching action.

Since grains of clay are so extremely small, some being composed of comparatively small groups of molecules, they contribute colloidal or gelatinous qualities to the soil. Water combines much more intimately with clay than it does with granular soils. The percentage of water may vary even on the same site. In one bed of clay investigated by the writer the percentages of water varied irregularly from 16 per cent. to 26 per cent. based on the weight of water to total weight of soil. Numerous bearing tests at various parts of the site

showed no parallelism between the water contents and the bearing values.

Air is present in soils, small percentages are present even in heavy clays. Tests by the writer indicate that this air, confined in the minute interstices of clay soils, contributes to the elasticity of such soils under loads that are not sufficient to break down the soil structure.

The structure of natural soil varies from that of granular sands and gravels to that of cohesive, gelatinous clays.

LINES OF PRESSURE AND DISTRIBUTION OF LOAD.

As to the distribution of load, there is a great difference between granular and cohesive soils.

In a granular soil, lines connecting the centers of the grains are zigzag, and a vertical load, on the surface of the soil, tends to buckle these lines, setting up lateral pressures against the surrounding grains. These lateral pressures, combined with the diagonal pressure due to shear, cause secondary laterals. The resultant lines of pressure gradually curve away from the vertical and up towards the surrounding surface.

In a cohesive soil, the diagonal tension, resulting from shear, draws down the surrounding soil, forming a depression in the surface.

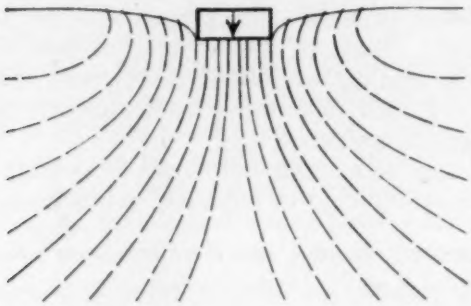
Figure 1 shows curves of "lines of pressure," from tests made by the writer on two artificial soil mixtures, and on a block of rubber. It is believed that they illustrate reasonably well the lines of pressure under loads on different types of soil, and that they aid in the interpretation of bearing tests.

Agreement may be noted between the phenomena resulting from load tests on the two extreme types of soil, illustrated on Figs. 2 and 3, and the phenomena that might be anticipated from a study of the different lines of pressure.

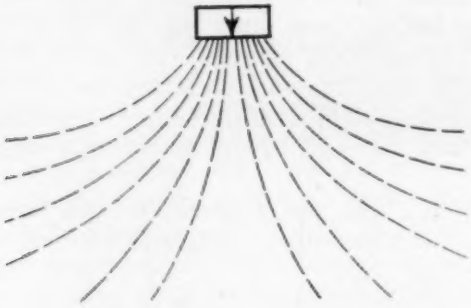
BEARING TEST ON A GRAVEL SOIL.

A bearing test was made on the surface of a foundation bed of natural, coarse sand and gravel. Ames gauges, in duplicate, measured to the thousandth of an inch the direct settlement of the load, while similar gauges, in contact with disks on the surface of the surrounding soil, measured the minute upheavals.

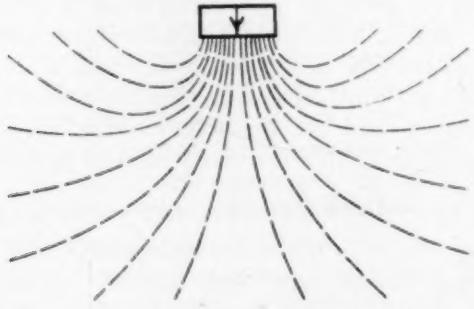
FIG. 1.



Pressure curves as estimated for a cohesive clay soil. From tests on a block of sponge rubber.

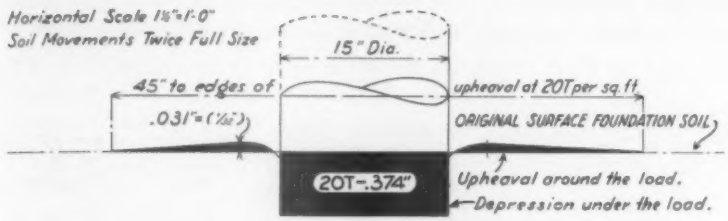


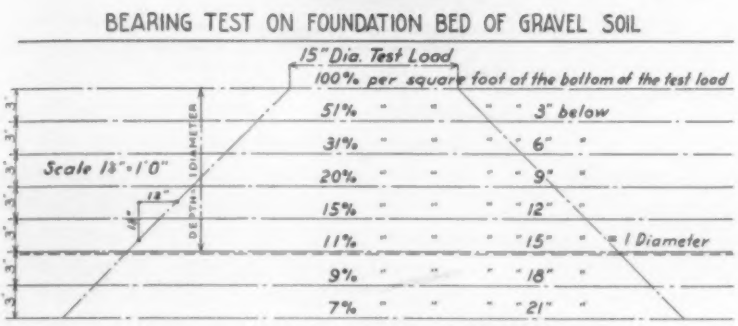
Pressure curves from test on artificially placed sand on top of muck.



Pressure curves from test on artificially placed sand. Full depth.

FIG. 2.




BEARING TEST ON FOUNDATION BED OF GRAVEL SOIL
15" Dia. Test Load
100% per square foot of the bottom of the test load
51% " " " " 3" below
31% " " " " 6" "
20% " " " " 9" "
15% " " " " 12" "
11% " " " " 15" " = 1 Diameter
9% " " " " 18" "
7% " " " " 21" "
Scale 1½"=1'0"
1 DIAMETER
DEPTH
18"
18"
3" 3" 3" 3" 3" 3" 3" 3"

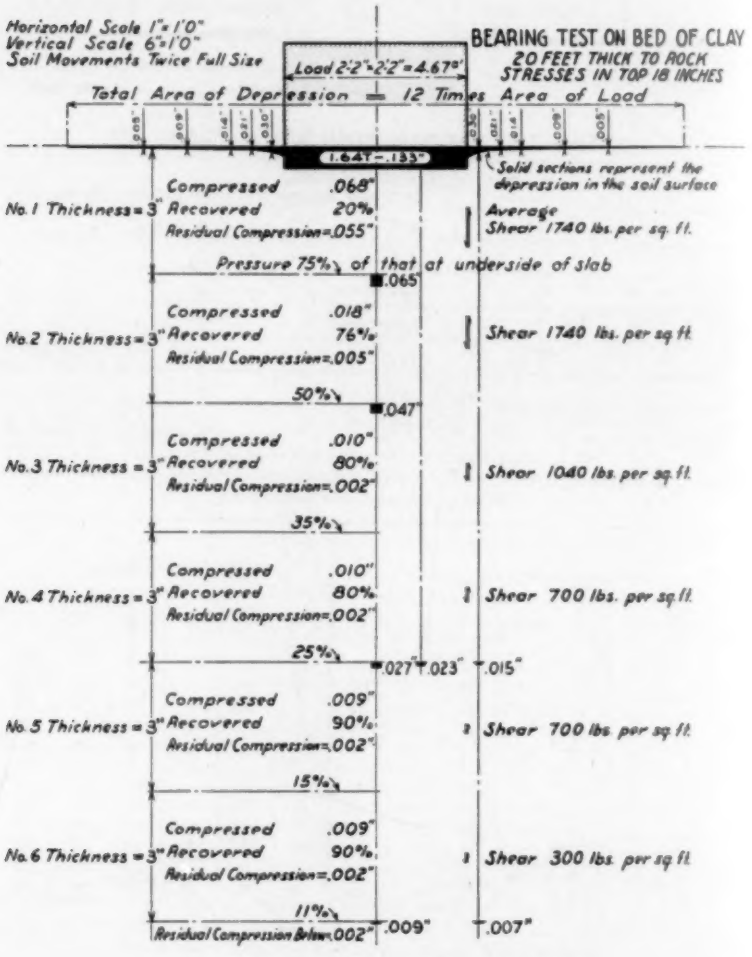
APPROXIMATE LOAD DISTRIBUTION IN THE GRAVEL SOIL
Pressures on underlying layers at various depths, in percentages of load per square foot on surface
(Based on truncated cone assumption)

Soil Depth \ Side Fig.	Square Isolated Footings						Continuous Footings					
	2' 0"	4' 0"	6' 0"	8' 0"	10' 0"	12' 0"	2' 0"	4' 0"	6' 0"	8' 0"	10' 0"	12' 0"
First Foot 0"	100	100	100	100	100	100	100	100	100	100	100	100
3"	64	79	85	89	91	92	80	89	93	94	95	96
6"	45	64	74	79	83	85	66	80	86	89	91	92
9"	33	53	64	71	76	79	57	73	80	84	87	89
1' 0"	25	45	56	64	70	74	50	67	75	80	83	86
2' 0"	11	25	36	45	53	56	33	50	60	67	71	75
3' 0"	6	16	25	33	39	45	25	40	50	57	61	67
4' 0"	4	11	18	25	31	36	20	33	43	50	56	60
6' 0"	2	6	11	16	21	25	14	25	33	40	47	50
8' 0"	1	4	7	11	15	18	11	20	27	33	38	44
10' 0"		3	5	8	11	14	9	17	23	29	33	38

PRESSURES IN GRANULAR SOILS IN PERCENTAGES OF PRESSURE AT THE BOTTOMS OF FOOTINGS
Heavy Line is at a depth equal to the side or width of the footing
(Based on truncated pyramid assumption)

The loading mast was a 15″ pipe filled with solid concrete. Bottom of the mast was bedded on a layer of quick setting grout paste to bring uniform bearing on the surface of the

FIG. 3.


Horizontal Scale 1"=1'0"
Vertical Scale 6"=1'0"
Soil Movements Twice Full Size
BEARING TEST ON BED OF CLAY
20 FEET THICK TO ROCK
STRESSES IN TOP 18 INCHES
Load 2'2"×2'2"=4.67#
Total Area of Depression = 12 Times Area of Load
1.641"-.135"
Solid sections represent the depression in the soil surface
No.1 Thickness=3" Compressed .068" Recovered 20% Residual Compression=.055"
Average Shear 1740 lbs. per sq. ft.
Pressure 75% of that at underside of slab
.065"
No.2 Thickness=3" Compressed .018" Recovered 76% Residual Compression=.005"
Shear 1740 lbs. per sq. ft.
50%
.047"
No.3 Thickness=3" Compressed .010" Recovered 80% Residual Compression=.002"
Shear 1040 lbs. per sq. ft.
35%
No.4 Thickness=3" Compressed .010" Recovered 80% Residual Compression=.002"
Shear 700 lbs. per sq. ft.
25%
.027" .023" .015"
No.5 Thickness=3" Compressed .009" Recovered 90% Residual Compression=.002"
Shear 700 lbs. per sq. ft.
15%
No.6 Thickness=3" Compressed .009" Recovered 90% Residual Compression=.002"
Shear 300 lbs. per sq. ft.
11%
Residual Compression Below .002" .009" .007"

soil. The loaded area was 1.23 sq. ft. The load was applied without impact, by an hydraulic jack, with slight pauses to allow the soil grains to come to rest under each increment of

load. The upper end of the jack reacted against a girder spanning between a counterweight and an adjacent building.

This natural soil consisted of pebbles, gravel and sand, very compact, weakly cemented by clay and iron oxide. Banks of the excavation would stand almost vertically a height of six to eight feet. Tests showed that the soil resistance to tension was twenty to sixty pounds per sq. ft. It was a type of soil usually considered safe for about 6 tons per sq. ft. under actual footings.

Under a test load of 5 tons per sq. ft., the direct settlement of the mast was 1/16″; under 10 tons per sq. ft., the direct settlement was a little over 1/8″; and under 20 tons, it was 3/8″.

The maximum upheavals corresponding to these loads were 1/120″, 1/70″, and 1/32″ respectively. The diameter of the crest of each of the upheavals was about 22″; the diameters of the outside edges of the upheavals under the successive loads were 30″, 35″, and 45″ respectively.

Figure 2 gives the cross-section of the conditions under the load of 20 tons per sq. ft. The measured upheavals, even though minute, showed that stress reached the surface over an area up to nine times the area of the load.

When the test load was released, the recovery was 30 per cent. of the total settlement. The total settlement was due to three related phenomena.

(1) The elastic compression in the soil, as shown by the recovery	30%
(2) The inelastic compacting of the soil, estimated as	35%
(3) The forcing of the grains sidewise and upward, as shown by the upheavals, roughly computed as	35%
Total	100%

Assuming the distribution of the stress in the soil under an isolated footing to be indicated by the "lines of pressure," the distribution will vary in the different types of soil.

The unit pressures on horizontal planes beneath loads applied on artificially placed sands have been investigated by Enger, Farr, Goldbeck and others. But for comparative studies, in estimating the approximate pressures on different levels in gravel soils, a very rough approximation may be made, based on the assumptions that the vertical pressures

are uniform over the various horizontal planes and that the stresses spread out in the form of a truncated pyramid (or cone), the top being the base of the load with the side elements at an angle of 45°.

In the center of Fig. 2, the percentages of vertical stress on horizontal planes at various depths below the bottom of the test load are given.

At the bottom of the same Fig. 2 are given the percentages of pressure that would occur, according to this assumption, under isolated footings of various sizes. Under such footings, the loads can spread out in all directions, but under continuous footings, since the stresses can only spread laterally in opposite directions, the reduction in stress is much less rapid at succeeding depths.

Under footings closely grouped, the stresses from adjacent footings overlap, and the net reductions are correspondingly limited.

(1) From the truncated pyramid assumption, it can be seen that the larger the footing, the larger the pyramid, and the greater the depth of the soil which is stressed to the same amount, with a correspondingly greater *elastic* deformation, or settlement.

(2) The settlement due to *inelastic* compacting, which occurs mainly in the highly stressed upper layers, probably increases in somewhat the same ratio.

(3) That part of the settlement which is due to the forcing of the grains, sidewise and upward, mainly from under the outer edges of a footing, probably decreases as its size increases because the perimeter increases less rapidly than the area.

BEARING TESTS ON A CLAY SOIL.

In the test on an actual foundation bed of a firm cohesive clay soil, measurements were taken not only on the surrounding surface, but also to a depth of 18″ below the load.

The load was applied through a steel slab, 3″ thick, 26″ square (4.7 sq. ft.), bedded on plaster of Paris. Fourteen gauges were placed on a line across the slab and beyond to measure the movements of the slab and of the surrounding soil. Holes through the slab at several points allowed the

soil below to be cored out, permitting measurements of vertical movements at various depths as the load was applied.

The water in the soil weighed approximately one-fifth of the total weight of the soil which was of an ordinary clay type, with a small percentage of fine sand, usually considered good for 2 to 3½ tons per square foot.

Separate tests showed that the clay had a shear value up to 1,800 pounds per square foot.

Fig. 3 is a cross-section showing, to a magnified vertical scale, the area and depth of the depression in the surrounding soil caused by a load of 1.64 tons per sq. ft. on the steel slab, the direct settlement of the slab being .133″, or slightly over 1/8″.

The compressions in each succeeding 3″ of depth of soil under the slab are given and also the percentages of recovery on the removal of the load.

By comparing the measured compression in each 3″ thickness with a scale of unit compressibility determined for this soil, the reduced percentage of pressure for each increment of depth was estimated. The punching shear at each level was also found and is noted under the right hand edge of the slab.

The load stressed the natural structure of the clay under the slab in the top 3″ beyond the elastic limit and the grains were crushed closer together and compacted. This effect was accompanied by a slight shearing of the top of the clay around the edge of the slab. Much less damage to the soil structure and greater recoveries were noted for succeeding depths. At the 18″ depth beneath the slab, the clay showed a high percentage of elastic recovery and at this same depth, just off the edge of the slab, the clay showed full elastic recovery.

The test recorded is typical of four other similar tests at the same site. After the test was completed and the load was removed, further measurements were taken as the load was reapplied and then increased from 1.64 tons to 2.17 tons per sq. ft. The top portions of clay showed greater resistance to compression, due to the compacting under the first load. In the top 3″ layer, the deformation under the second application was only 2/3 of that under the first application.

The lower layers showed deformations proportionate to the increased load, and almost perfect elastic recovery.

Because the top layers of clay were stressed beyond the elastic limit, the actual stresses in the different layers could not be determined directly from the unit compressibility for this clay. "Cut and try" assumptions were made until stresses were reached that seemed consistent with each other and with the measured deformations.

The stresses seemed to decrease inversely as the depth, more rapidly by the truncated pyramid assumption. The pressure on the clay, at a depth of 18″ below the load, was found to be only 11 per cent., instead of 18 per cent. according to the truncated pyramid assumption. This indicates a wider load distribution. Comparing the test load on the gravel bed with that on the clay, it was found that the average direct settlement per ton per sq. ft. on the gravel was .374″/20 = .019″, while that on the clay was 1.33/1.64 = .080″, or four times as much.

But the unit compressibility of this clay is estimated to average ten times that of the gravel, and since the settlement per ton was only four times as much, this also indicates a wider distribution of load by the clay.

However, on another part of the same bed of clay, the distribution of load was much less pronounced; the area of the surface depression was only half as large and the direct settlement was twice as much.

On another bed of clay, a saturated and much softer clay, the area of the surface depression was very small and the direct settlement was five times as much.

In estimating the settlement of large footings, the distribution area of a test load seems to be an important factor.

INFLUENCE OF TENSION IN CLAY SOIL BEARINGS.

A clay cylinder was carefully cored out of a foundation bed of very cohesive clay; the moisture was 16 per cent. of the total weight. The cylinder was 2″ diameter, 4¾″ long and the central part of its length was carved down to a reduced, straight section, $1\frac{3}{16}$″ square by 1.2″ long between two needle points. At each end of the reduced section, the clay beveled out to the 2″ diameter section, forming a suitable tension

specimen. The round ends were encased by clamps, and the specimen was hung vertically by the upper clamp, while weights were hung from the lower one. The load was increased slowly to the equivalent of one ton tension per sq. ft., which the specimen held for 20 minutes, after which it broke at a fine crack. Readings were taken during the test, of the elongation of the test specimen between the needle points.

At a tension equivalent to .66 ton per sq. ft. the elongation was about .200″ per ton per sq. ft. per foot of length. The elongation remained constant for 15 minutes, then the load was removed. The elastic recovery was 2/3 of the elongation. At the ultimate load of one ton per sq. ft., the proportionate elongation was also equivalent to .200″ per foot of length per ton per sq. ft.

This tension test may be considered as only an indication of the elastic tension that may occur in a very cohesive clay soil, but since clay is capable of resisting shear, diagonal tension, and horizontal tension, it indicates that a cohesive clay under, and adjacent to, a load becomes, in effect, a "sub-soil-spread-footing." Under the 26″ square test load, the clay "footing" approximated a size 7 feet square, 18″ deep. This conception, of a "sub-soil-spread-footing," shows the possibility of a foundation on clay settling when the adjacent soil is cut away; and it also shows the necessity of considering the settlement that may result when foundations on clay are placed so close together that their "sub-soil-spread-footings" overlap.

COMPARISON OF THE TWO TESTS.

Two tests have been presented, one on the granular type, one on the cohesive type. They are at opposite ends of the usual range of bearing soils. In both tests, each succeeding inch of soil spread the load over a larger area. There the similarity ends. In the test on gravel soil, the surrounding soil was elevated, in the one on clay, it was depressed.

If, while the test load was being applied on the surface of the gravel, a light surcharge had been applied simultaneously on the surface of the adjacent gravel, just sufficient to prevent upheaval, the direct settlement of the load would probably have been less, but if any surcharge had been ap-

plied simultaneously around the test load on clay, the direct settlement would have been more. A footing may be considered as having an inner area, equal to a test load area, and an outer area, surrounding the inner one.

Of course, as a structure is erected on the footing, both the inner and the outer areas of the footing are loaded simultaneously. In the case of a gravel soil, the load on the outer area prevents any upheaval from load on the inner area. To that extent, the loads on the two areas minimize the settlements of each other.

In the case of a clay soil, the load on the inner and that on the outer areas increase the settlements of each other.

No one formula can be applied to both gravel and clay soils when estimating the settlement of footings. It is necessary, rather, to study the soil phenomena connected with the settlement of loads on each type of soil.

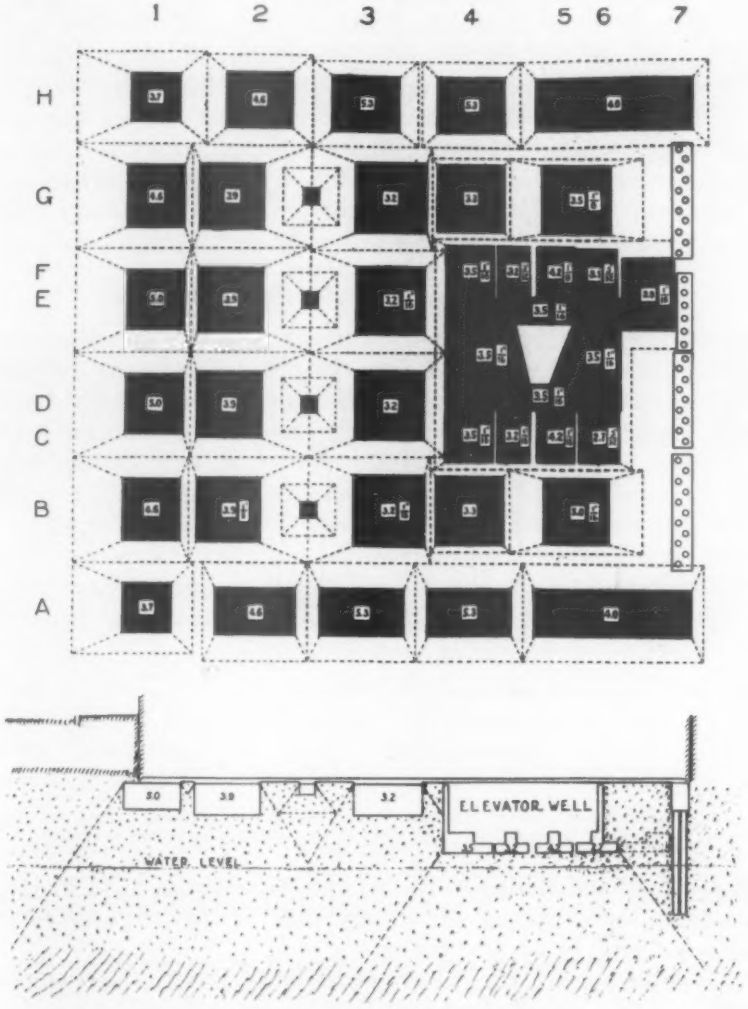
APPLYING THE DATA FROM THE TEST LOAD ON GRAVEL.

On the bed of gravel soil on which the test was made, a twenty-seven-story office building was to be erected. The test load data indicated that spread, reinforced concrete footings could be used for the foundations. The footings were all designed, under the direction of the writer, as chief engineer for the architect, for the total dead load, plus live loads, reduced as allowed by the local building code. The footings which had to be placed close together were, however, designed for a somewhat lower total load per sq. ft. of soil bearing, to allow for the overlapping of soil stresses. After the building was erected, the actual pressures, caused by the dead weight of the buildings, were computed. Levels were taken, to previously established marks, to measure the settlement of each footing. For most of the 26 isolated footings, with sizes approximating 10 feet square, the settlements were so small that they could not be detected with the level, and, therefore, they probably did not exceed 1/32″. Figure 4 shows the recorded settlements.

But, each of the 13 footings that had to be placed close together in the elevator pit showed small settlements ranging from 1/16″ to 1/8″. The few isolated footings which showed

similar small settlements were mostly those adjacent to the edge of the upper part of the elevator pit.

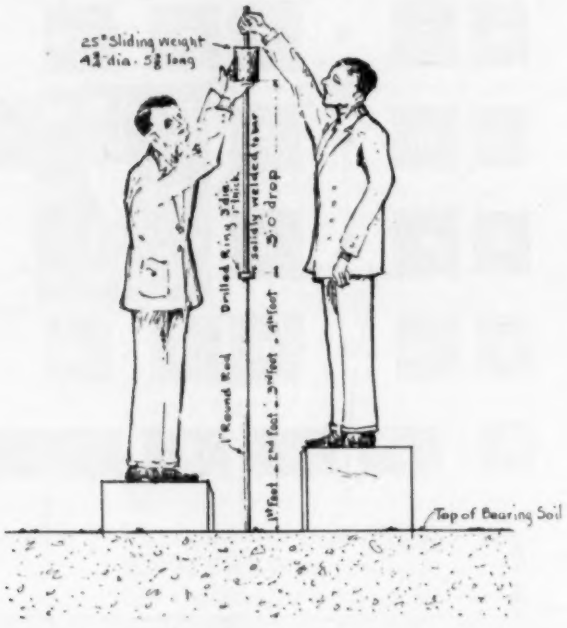
FIG. 4.



To compute settlements, to compare with the actual settlements, the truncated pyramid assumption may be used for an average footing, 10 feet square. From the table,

Fig. 2, under a footing 10 feet square, the average percentage of stress in a vertical column of soil, 10 feet deep, is 34. Stresses below this depth, which is equal to one side of the footing, have been ignored because the average stress below this level is very small. Using the unit of total compressibility of .008″, per ton per sq. ft., per foot depth, and assuming the elastic compressibility as 30 per cent. of the total compres-

FIG. 5.


25# Sliding weight
4½" dia. · 5ft long
Drilled ring 3/4in. Thick
Round Rod
1st foot = 2nd foot = 3rd feet = 4th feet = 3'0 drop
Top of Bearing Soil

Kneas—Drop-Penetration Test of Bearing Soil. Each drop of the 25-lb. weight is 3′-0″; penetration of the 1″ bar into the soil is recorded for the number of blows for each foot.

sibility, the shortening of the 10 foot soil column for a footing load of 4 tons per sq. ft. equals .008″ × 30% × 4 × 10 × 34% = .033″ or about 1/32″.

Ordinarily to the above computed elastic settlement .033″, for an average ten-foot footing, there should be added an allowance for the inelastic compacting in the top layers, but apparently under these footings this compacting was negligible.

Nothing needs to be added for any settlement due to the side slipping, because the holes to receive the footings were dug to exact size, and the concrete was placed in direct engagement with the gravel on each side of the footing. In fact, the load per sq. ft. on the bottom of the footing was reduced by the amount that was distributed by shear, and by diagonal compression, into the adjacent soil by the grip of the concrete on the soil at each side of the footing. It is noteworthy that most settlements occurred in the footings within the elevator well. While the settlements were very small, they confirm the theory that it is desirable to use lighter loads on footings that have to be placed close together.

APPLYING THE DATA FROM THE TEST LOAD ON CLAY.

On the bed of clay, three machine foundations were to be erected, twenty-six feet wide and forty-four feet long. Each was to receive a machine, weighing about 750,000 lbs., resting on three main bearings along the length of the footing. The requirement was that under the dead weight of the machine, there was to be no unequal settlement in excess of .013″.

From the results of the test data, it was thought that bearings on the clay alone would not meet this severe requirement, and in order to meet it, and to prevent vibration passing through the soil from one foundation to those adjacent, concrete-filled-pipe-piles were used in the design. From the tests on clay, and those on the piles, it was believed that the clay and the piles, together, would support a reinforced concrete foundation that would meet the requirement. Upon completion of the foundation, machined bronze plugs were set in the concrete. After the erection of the 750,000 lbs. machine, elaborate checking, by precise levels, showed that the unequal settlement, due to the dead weight of the machine on this concrete foundation 26′ × 44′, was only .011″.

TENTATIVE CONCLUSIONS FROM THE BEARING TESTS.

1. To interpret bearing tests, it is necessary to know what deformations are occurring in the soil, under, and surrounding the load, and to evaluate the elastic deformation, the inelastic compacting and the side slip of the grains.

2. No one formula can be used for all types of soil, since the phenomena connected with settlement in the granular type of soil are quite different from those in the cohesive type.

3. The soil under a foundation forms, in effect, secondary sub-soil-spread-footings, especially in clay soils, and in all cases a portion of the load is distributed laterally into the surrounding soil beneath the foundation.

4. Under continuous footings where high stresses penetrate to greater depths than under isolated footings and under closely grouped footings, whose sub-soil stresses overlap, it is desirable to use lower allowable soil bearing values.

5. The cutting away of the "soil-sub-footings," by excavating close beside existing footings, may lead to serious settlements, especially in soils of the clay type.

DROP PENETRATION TESTS.

The making of a load test on a bearing soil complete enough to allow an analysis of the different elements of settlement, is justified in connection with the design of important foundations. But, after a load test is made, supplemental tests are necessary to determine whether the results are representative of the values of the soil at other parts of the site. The bearing values at different parts of the same bed of soil differ, and, sometimes, they differ widely.

To detect such differences, the engineer will, in many cases, sound the soil by driving into it a shovel, a pick, or a bar. Made by an experienced man, these soundings are of value, but the personal equation enters very largely. From actual comparative results of a total of 600 blows the writer has found that, in a favorable position, the same man will deliver a hammer blow three times as effective as when he is in a less favorable position. He will also, instinctively, vary his blows with the variations in the soil, striking more gently when the penetration is easy, and harder when the soil is more resistant.

If these differences are ignored, the same soil will, in one case, be considered three times as resistant to the driving rod as in the other; in other cases the actual variations will not be shown on account of the differences in driving.

To avoid drawing erroneous conclusions from such tests

the writer, some years ago, devised the Drop-Penetration test, a sketch of which is shown in Fig. 5.

This device always delivers the same driving effect per blow, even in the hands of unskilled laborers, because the weight is always 25 lbs., and the drop is always 3 feet. It can be used in narrow test pits where a hammer cannot be swung. It is also safer, as it avoids the danger from glancing blows of a heavy hammer in unskilled hands.

The number of blows required to drive the bar each foot into the soil to a depth of four feet, will indicate not only the varying soil resistances at different locations on the site, but will also indicate the varying resistances beneath the surface to depths of four feet.

Very frequently, a less resistance is found several feet below the surface, but when the difference is not great, and the fewer blows still indicate sufficient resistance, the bearing may be found satisfactory, or the footing may be slightly enlarged. When the drop-penetration test shows few blows near the surface and greater resistance below, the desirability of dropping the footing to a lower level is indicated.

When the soil is found soft at a four foot depth, a driving rod may be used to sound to greater depths, even to fifty feet. This depth was reached, in a test by the writer, through layers of sand and gravel and soft clay of varying resistances, by welding additional sections to the rod as it was driven into the soil. The readings were found to be reliable by results from open pipe piles driven later. In the driving and the cleaning out of the pipes, soft material was found at the depths indicated.

As an indication of the effect of the 25 lbs. weight falling 3 feet, it is noted that it took 18 blows to drive a bar 12″ into a very compact gravel soil, it took a direct load of 600 lbs. to force the same bar to the same penetration.

Some typical records of drop-penetration tests are given below for soils whose bearing values were decided by building codes or by average practice. Each record gives the average values of three to eighteen tests.

Of course, neither load, nor driving rod, nor drop-penetration test will automatically determine a soil bearing value. Each test requires experienced judgment for its interpretation.

Blows of 25 Lbs. Weight Falling 3'–0".

Penetrations	Granular Soils					Cohesive Soils	
	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F	Soil G
1st foot	22	19	10	5	3	9	5
2nd foot	30	34	24	9	10	20	13
3rd foot	52	39	40	16	13	32	20
4th foot	62	28	—	26	16	40	24
Bear. val. sq. ft.	6 tons	6 tons	4½ tons	3 tons	2 tons	3½ tons	1½ tons

Soils A, B, C were compact sand and gravel soils, Philadelphia, Pa.

Soil D was a sandy soil at Atlantic City, N. J.

Soil E was a loose, glacial sand and gravel, northern part Pennsylvania.

Soil F was a firm sandy clay, moisture about 20 per cent. of total weight.

Soil G was a rather soft, plastic clay, moisture about 26 per cent. of total weight.

ACKNOWLEDGMENTS.

The writer wishes to express his sincere appreciation to those who made the soil tests possible, to the engineers who assisted in the instrument work and computations, and to those who reviewed the manuscript.

GRAPHICAL ANALYSIS OF TRANSIENT PHENOMENA IN LINEAR FLOW.*

BY

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I. INTRODUCTION.

In physical systems comprising masses and forces a certain state of equilibrium corresponds to any and each given set of conditions. Whenever in such a system the existing set of conditions determining the initial state of equilibrium is altered the system will assume the state of equilibrium corresponding to the altered set of conditions. It is an inherent property of all physical systems that time is required for such a readjustment even if the change of conditions be impressed on the system instantaneously. The varying states through which the system passes in this interval of time are called transients.

This paper will treat transient phenomena in fluid flow. In general the state of fluid is characterized by its coördinates of state, i.e., pressure p, velocity v and temperature T, each of which is a function of the three spatial coördinates x, y, z and also of time t. Our treatment, however, will be restricted to cases in which the influence of changes of temperature T can be neglected; furthermore we shall deal only with systems in which the importance of one coördinate, the distance x from the point of origin, is predominant, i.e. in which the flow is linear and the state of flow does not change in the various y, z points of a given cross section.

Linear flow of this type occurs in pipe lines of turbines and water-works, furthermore in the fuel-injection systems of Diesel engines. The transient phenomena occurring at the sudden acceleration and deceleration of the liquid exert an important influence on the functioning of such systems. The following treatment will apply primarily to such hydraulic

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systems. Nevertheless the method and results are also applicable to the response to a disturbance of other linear systems which are endowed with elasticity and inertia, such as to surges in mechanical springs and in gas columns and even to transient phenomena in electrical conduits.

II. STATEMENT OF THE PROBLEM.

In a hydraulic system the transient changes of velocity and pressure depend on the dimensions and characteristics of the system and on the characteristics of the disturbance. The problem can be stated as follows:

Knowing: the dimensions of the hydraulic system, its initial condition of equilibrium and the characteristics of the disturbance as a function of time t,

Determine: the response of the system as expressed by the values of velocity v and of pressure p of the liquid at any point x in the system as a function of time t.

In mathematical terms, the problem is considered solved when the pair of functions

$$v = f_1(t, x), \tag{1}$$

$$p = f_2(t, x) \tag{2}$$

have been determined.

In graphical terms each of these functions can be represented by a stereogram with the v respectively p values as vertical ordinates erected over the t–x plane as base. Our purpose is to find, by graphical methods, the data from which this pair of stereograms can be constructed. Such a pair of stereograms if actually built as solid models enable one to visualize clearly the process of change in the hydraulic transient. A section of such a model with an x = const. plane will give the history of velocity, resp. pressure at that particular point in the system; a section with a t = const. plane will give the velocity and pressure values at all points of the system at one particular instant. The plane view of these stereograms shows the lines of discontinuity in the three-dimensional surfaces, caused by the disturbance of the velocity and pressure condition. As will be shown later the disturbance of velocity involves also a change of pressure, and vice-

versa, therefore the disturbance-lines, as represented graphically on the t–x plane, i.e. the plane view, will be the same for both the v and p stereograms.

As it will be shown later the two functions v and p are not independent of each other but are interconnected by the function

$$f_3(v, p) = 0, \tag{3}$$

representable by a two-dimensional diagram in which any point, with its two coördinates of velocity and pressure, defines a state of flow. It will be found that this v–p diagram is of fundamental importance for the graphical method of computation.

III. DEFINITION OF HYDRAULIC ELEMENTS.

Any hydraulic system can be considered as the combination of the Liquid and two or more of the following elements: Pump, Pipe, Nozzle, Storer and Swinger, which in the following will be defined and their representation in the time-diagram or in the velocity-pressure diagram be discussed.

(*a*) *The Liquid* is characterized by its compressibility and by its acoustic velocity:

$$k = \sqrt{\frac{dp}{dV}}, \tag{4}$$

$$a = \sqrt{kV}. \tag{5}$$

The ratio of the two

$$\frac{k}{a} = \sqrt{\frac{dp}{dV}}, \tag{6}$$

which is a constant for a given material, plays an important part in the derivations that follow. (In App. I, Table I, these values are tabulated for a number of liquid, solid and gaseous materials.)

(*b*) *The Pump* (Fig. 1) is a delivery organ by which liquid and energy is supplied to the system. It is characterized by its rate of delivery as a function of time:

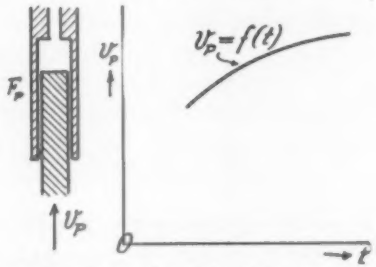
$$q_P = F_P v_P; \qquad v_P = \frac{q_P}{F_P} = f(t), \tag{7}$$

TABLE I.

Reference		Int. Cr. T	Hyde	Le Mesurier and Stansfield	Le Mesurier and Stansfield		Roth-rock	Davies and Giffen	Hersey	Alex-ander (Sass)	Hyde	Davies and Giffen	Int. Cr. T Bridg-man	Steel		Air 20° C. 30 in Hg
Material and Range		Water			Fuel Oils											
Property		40° C. 0–1000 at	20° C. 0–1417 at	45° C.	45° C. 0–200 at				20° C.	0–352 at	Lubr. Oil 40° 0–1102 at	Alcohol	Mercury	in Tension	in Torsion	
γ		1.0076			.840	.895	.860	.860	.864	.880	.899	.810	13.6	7.8		.0012
w	lb. in.$^{-3}$	.0388			.0303	.0323	.0310	.0310	.0312	.0317	.0324	.0292	0.491	0.282		.0000434
	kg m^{-3}	1,007.6			840	895	860	860	864	880	899	810	13,600	7,800		1.20
ρ	lb. in.$^{-4}$ sec.^{2}	.0001005			.0000785	.0000836	.0000804	.0000804	.0000808	.0000820	.0000839	.0000761	.001270	.000731		.0000001135
	kg m^{-4} sec^2	102.9			85.6	91.2	87.8	87.8	88.0	89.7	91.5	82.6	1,390	795		0.123
V	in.^{4} lb.$^{-1}$ sec.$^{-2}$	995			1,272	1,192	1,241	1,241	1,235	1,218	1,190	1,310	787	1,370		8,800,000
	m^4 kg^{-1} sec^{-2}	.00975			.01165	.01095	.01140	.01140	.01135	.01115	.01091	.01218	.000718	.00126		8.15
k	lb. in.$^{-2}$	370,000	376,000	314,000	258,000	284,500	284,000	266,000	284,000	294,000	327,000	180,000	3,525,000	31,250,000	12,200,000	20.0
	kg cm^{-2}	26,000	26,500	22,100	18,200	20,000	20,000	18,750	20,000	20,750	23,000	12,650	248,000	2,200,000	860,000	1,405
a	ft. sec.$^{-1}$	5,210	5,260	4,800	4,775	4,850	4,950	4,780	4,940	4,980	5,200	4,060	4,365	17,300	10,800	1,110
	in. sec.$^{-1}$	62,600	63,100	57,700	57,200	58,200	59,400	57,400	59,200	59,800	62,300	48,800	52,400	207,500	129,500	13,400
	m sec^{-1}	1,590	1,605	1,465	1,455	1,480	1,510	1,460	1,505	1,520	1,585	1,240	1,332	5,270	3,290	340
$a\bar{k}$	lb. in.$^{-2}$ ft. sec.$^{-1}$	71.0	71.5	65.5	54.1	58.8	57.5	55.8	57.2	59.1	62.8	44.4	810.0	1810.0	1130.0	0.0181
	kg cm^{-2} m sec^{-1}	16.35	16.50	15.10	12.50	13.50	13.25	12.85	13.30	13.65	14.50	10.20	185.50	417.0	261.0	0.00435

in which F_P = plunger area and v_P = plunger velocity, which latter can be represented graphically as a function of time. This function is supplied by the conditions of a given problem (e.g., by the cam shape and the camshaft speed). The de-

FIG. 1.



Representation of pump in the $v-p$ diagram.

livery of the pump is at every instant equal to the influx into the element (e.g., pipe, nozzle, or storer) directly adjoining to it.

(*c*) *The Pipe* (Figs. 2*a*, *b*) is a connecting organ which is

FIG. 2*a*.

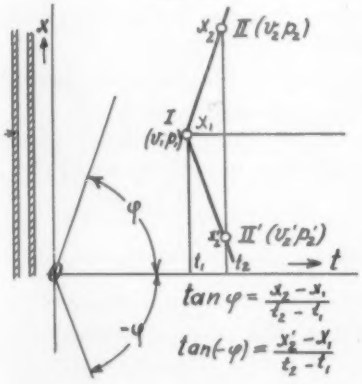
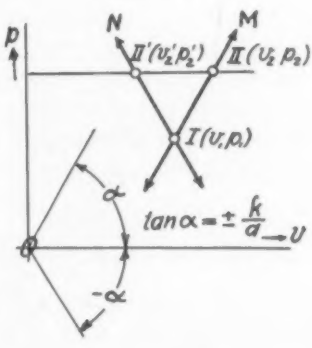


FIG. 2*b*.



Representation of pipe: (*a*) in time-distance diagram; (*b*) in velocity-pressure diagram.

characterized by its length L and by its cross sectional area F_L. In this analysis we deal with thick-walled pipes which can be considered non-yielding in the stress range under consideration.

In the t–x chart (Fig. 2*a*) the progress of a disturbance (e.g., changing from flow condition v_1p_1 to v_2p_2) originated at the instant t_1 at the point in the pipe x_1 can be represented by two sloping lines, which may be called "disturbance lines" showing the points in the pipe (x_2, x_2^1) reached by the disturbance at the instant t_2. The slope of these lines represents the velocity of propagation:

$$\frac{x_2}{t_2} - \frac{x_1}{t_1} = \tan \varphi = a,$$
$$\frac{x_2^1 - x_1}{t_2 - t_1} = \tan (-\varphi) = -a, \tag{8}$$

the value being positive or negative according to whether the disturbance travels away from, or towards, the point from which the distances are measured.

In most problems of transient phenomena pipes have a finite length L. The time necessary for a disturbance to traverse the pipe from one end to the other, i.e.

$$T = \frac{L}{a} \tag{9}$$

is an important constant and is called the "interval of single traverse" or briefly "the interval."

In the pipe energy may be present in both forms as kinetic (velocity-) energy and potential (pressure-) energy.

From the continuity of flow and from the finite speed of propagation the following relationship can be derived:

$$\frac{p_2 - p_1}{v_2 - v_1} = \pm \frac{k}{d} = \tan (\pm \alpha), \tag{10}$$

i.e., in a pipe the change of pressure involves a proportionate change of velocity and vice versa, the proportionality factor being dependent on the elasticity and on the acoustic velocity of the liquid. (The derivation of this formula is given in App. II.) This is a dimensionally correct formula as on both sides of the equation the numerator is pressure, and the denominator is velocity.

This relationship can be represented in the v–p diagram (Fig. 2*b*) by two sloping straight lines which will be called

"directrices," with slopes $+ (k/a)$ and $- (k/a)$ respectively, passing through the (v_1, p_1) point characterizing the original condition of the flow. If, now, the flow condition is changed by a disturbance the new conditions of flow will be characterized in the diagram by another point (v_2, p_2) which will lie either on the positive or the negative directrix according to whether the disturbance travels away from, or towards the observer. Therefore one of the flow coördinates v_2 or p_2 determines the other.

In Fig. 2*b* the disturbance is illustrated on the v–p diagram, showing that the original conditions v_1, p_1 can be changed in four ways only:

(1) $v_2 > v_1$ and $p_2 > p_1$ } along directrix M (i.e., $+ \alpha$); the
(2) $v_2 < v_1$ $p_2 < p_1$ } disturbance travels away from the observer.

(3) $v_2 > v_1$ $p_2 < p_1$ } along directrix N (i.e., $- \alpha$); the
(4) $v_2 < v_1$ $p_2 > p_1$ } disturbance travels towards the observer.

FIG. 3*a*.

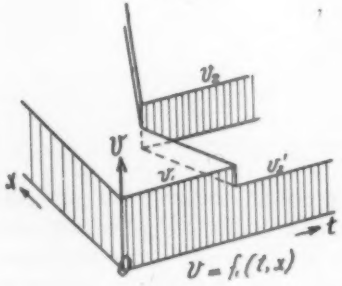
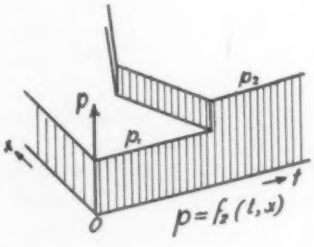


FIG. 3*b*.



Stereograms of disturbance in pipe: (*a*) velocity stereogram; (*b*) pressure stereogram.

The stereograms of velocity and of pressure uniting the Figs. 2*a*, *b* are shown axonometrically in Figs. 3*a*, *b*.

(*d*) *The Nozzle* (Fig. 4) is an efflux organ through which liquid and energy leave the system. It is characterized by the rate of discharge as a function of pressure:

$$q_N = F_N v_N = f(p),$$
$$v_N = \frac{q_N}{F_N} = f_1(p), \qquad (11)$$

in which F_N = effective orifice area which is constant or may be itself a function of pressure, and $v_N = f_1(p)$ the efflux velocity which is a function of pressure. The volume of the nozzle is negligible, therefore it can be stated:

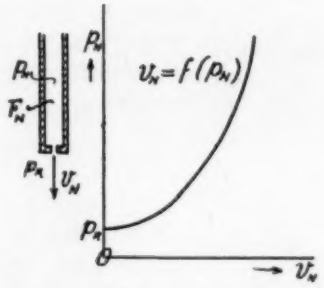
The rate of discharge from a nozzle is at every instant equal to the rate of delivery from the element (pump, pipe or storer) directly adjoining to it.

Furthermore, the length of the nozzle also being negligible, therefore:

The pressure at the nozzle is at every instant equal to the pressure in the element (pump, pipe or storer) directly adjoining to it.

(*e*) *The Storer* (other appropriate names for it might be

FIG. 4.



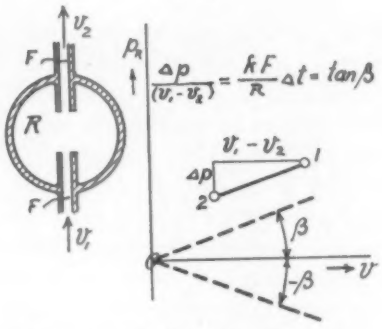
Representation of nozzle in $v-p$ diagram.

reservoir or accumulator) is a storage element for the liquid in which energy is stored in the form of pressure energy (Fig. 5). It is characterized by a relatively large volume and small length dimensions. Storers may be intentionally built into a system (e.g., in water systems the reservoir and the surge tank, and, in the so-called common-rail injection system, the accumulator); or they may be present incidentally and unintentionally, such as the widened portions of a pipe adjoining the nozzle, or a filter inserted in the injection pipe-line. It can be considered as "concentrated volume." The ideal storer has only volume and no length dimension, but of course physically this cannot be realized. The closest approach to this is a sphere into the center of which opens the pipe or pump. When flow takes place into, or out of, the storer the

flow is distributed over a large area; therefore the velocity and consequently the inertia effects of the liquid are reduced to negligible magnitude. Moreover, any pressure change taking place at the entrance can be considered as reaching the whole volume of the storer with negligible time-lag, i.e., instantaneously. Therefore the phenomena in the storer are characterized solely by the compressibility of the liquid; inertia effects can be neglected.

The characteristic equation of a storer expresses the interrelationship between the influx (or efflux) velocity difference $v_1 - v_2$ through an area F maintained during the time-interval Δt, and the resulting pressure change Δp in the storer. De-

FIG. 5.



Representation of storer in v–p diagram.

noting the volume of the storer by R and the compressibility of the liquid by k it can be written:

$$\frac{F(v_1 - v_2)\Delta t}{R} k = \Delta p,$$

whence

$$\frac{\Delta p}{(v_1 - v_2)} = \frac{kF}{R} \Delta t = \tan \beta, \tag{12}$$

which expresses that in a storer the change of pressure during a given time-interval is proportional to the velocity difference of efflux and influx. The graphical significance of the angle β is shown in Fig. 5. It can also be written:

$$R = \frac{\Delta Q}{\Delta p} k, \tag{13}$$

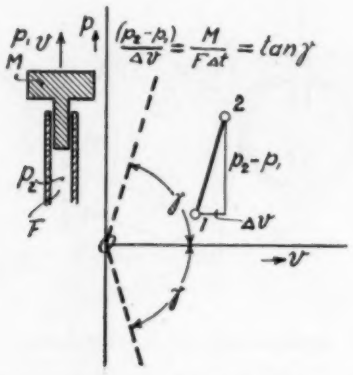
where

$$\Delta Q = Fv\Delta t,$$

from which the equivalent storer volume R for a device like a cylinder with spring-loaded piston can be calculated from the pressure increase Δp brought about by a volume influx ΔQ and from the compressibility k of the liquid.

(*f*) *The Swinger* (other appropriate name might be oscillator) is an inertia element such as a free plunger included in the pipe and moving therein without friction, acted upon by the liquid pressure, which is capable of absorbing energy in kinetic form (Fig. 6). Any velocity change taking place at

FIG. 6.



Representation of swinger in v–p diagram.

one end of the swinger is imparted instantaneously to its whole mass. Thus it is characterized by having only inertia but no compressibility. A swinger may be acted upon by the pressure of the liquid on both of its end surfaces, thus separating the liquid column into two parts, or it may be acted upon only on one of its end surfaces.

If a swinger is acted upon also by forces other than its own inertia, e.g., by its own weight, or by a spring force, then it acts not as a pure swinger, but as a combination of swinger and storer. Such combinations are common in hydraulic systems, e.g., spring-loaded safety valve on a penstock, or, a spring-loaded needle-valve in a nozzle.

The characteristic equation of the swinger expresses the interrelationship between the change of velocity Δv of a swinger with mass M when acted upon its cross-sectional area F by a pressure difference $p_2 - p_1$ during the time interval Δt. From the law of momentum it can be written:

$$(p_2 - p_1)F\Delta t = M\Delta v,$$

whence

$$\left(\frac{p_2 - p_1}{\Delta v}\right) = \frac{M}{F\Delta t} = \tan \gamma. \qquad (14)$$

The graphical significance of the angle γ is shown in Fig. 6. It expresses that for a given Δt time element the velocity change of a swinger is proportional to the pressure difference acting upon it.

In the foregoing characterization of hydraulic elements tacit approximations were made. Hardly any of these elements can be physically realized in its complete purity uncontaminated by the admixture of other elements. Thus a pump has in its compression space a storer inherently incorporated in it; a pipe acts, in virtue of its elastic expansion, also as a storer; a nozzle is in reality a short pipe; the storer's linear dimensions are not negligible, neither is the velocity of liquid in it zero; the swinger has some compressibility. In order to make an analysis practically possible, the dominant features of each element were emphasized, the secondary features disregarded. The approximations thus attained are close enough to the truth to base the graphical method of computation on them, from which usable conclusions can be drawn for practical applications.

IV. EXAMPLES OF COMBINATIONS OF ELEMENTS.

In possession of the characteristic representation of the component hydraulic elements in the t–x and v–p charts we are able to proceed to the solution of problems in transients. In each case we shall assume: (1) the composition of the system, (2) the initial state of equilibrium, and (3) the nature of disturbance. We shall seek to determine: (1) the stereograms $v = f_1(t, x)$ and (2) $p = f_2(t, x)$ and (3) the final state of equilibrium.

FIG. 7a.

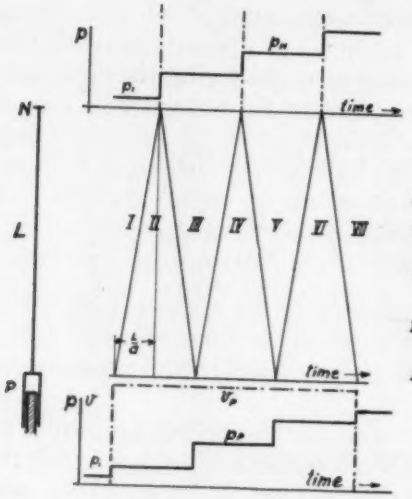


FIG. 7b.

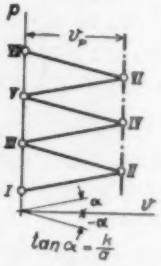


FIG. 7c.

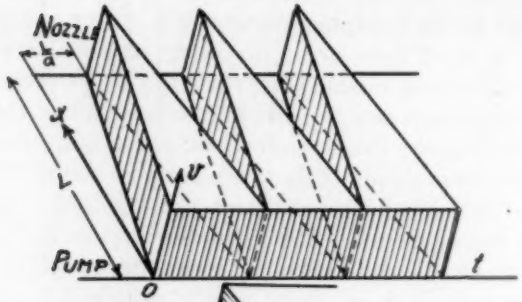
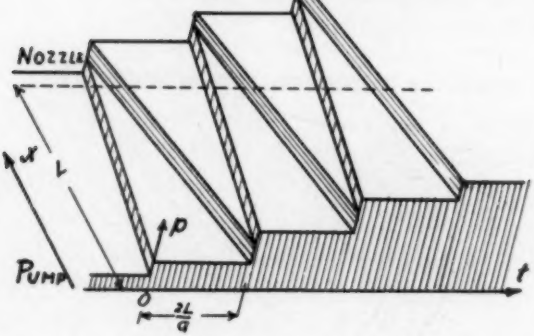


FIG. 7d.



Pump and pipe; constant plunger-velocity: (*a*) history diagram; (*b*) p–ϕ diagram; (*c*) velocity stereogram; (*d*) pressure stereogram.

1. Pump and Pipe (Figs. 7*a–d*, 8*a*, *b*, 9*a–d*).

First we shall consider the case of two elements, a pump to which a pipe, closed on the other end, is adjoining; the initial pressure in the system is p_1; initially the plunger is at rest ($v_P = 0$); at the beginning of our time reckoning the plunger starts to move and the motion lasts for a given time. Three cases will be treated:

(*a*) plunger velocity constant, duration of motion is an even multiple of an L/a interval;

(*b*) plunger velocity variable, duration of motion is an even multiple of an L/a interval;

(*c*) plunger velocity constant, duration of motion is a fractional multiple of an L/a interval.

The case (*a*) is represented in Figs. 7*a–d*. The initial state of the liquid ($v_P = 0$; $p = p_1$) is denoted by point *I* which holds good for the zone *I* in the v–p diagram. The characteristic of the pump is represented in the v–p diagram by the v_P = const. line. The rise of velocity in the pipe to v_P originated by the plunger is accompanied by a pressure rise p_2 as designated in the v–p diagram by the point *II* found by intersecting the v_P = const. line with the directrix (line of k/a slope) drawn from point *I*. Since the other end of the pipe is closed the arriving wave is stopped and the return waves are characterized by $v_N = 0$ as designated by points situated on the $v = 0$ ordinate axis. On reaching the closed end of the pipe the flow comes to a standstill ($v = 0$), which change is accompanied by a change of pressure as given by point *III* in the v–p diagram, found on the negative directrix drawn from point *II*. This wave is reflected towards the plunger and when it reaches the plunger its velocity is again brought up to v_P as denoted by point *IV* in the v–p diagram. In this manner the process progresses to conditions denoted in the diagram by points *V*, *VI* and *VII*, which latter represents the final condition of the liquid after the plunger came to rest.

From the data on the v–p diagram the velocities and pressures at the pump-end and the closed end of the pipe can be plotted on a time basis, as shown in Fig. 7*a*, by the v_P = const. line and by the stepped lines p_P and p_N. The shorter the pipe the more numerous the steps are during a given period of time (as the L/a time interval is shorter). And the lower

FIG. 8a.

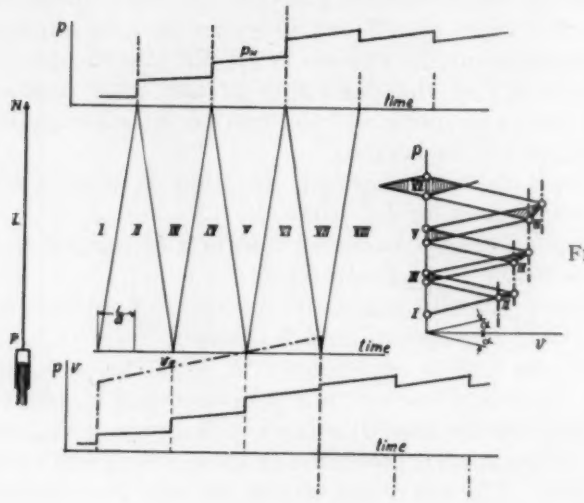
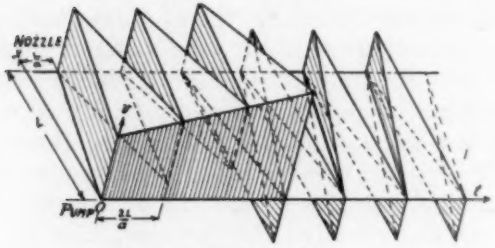


FIG. 8b.

FIG. 8c.



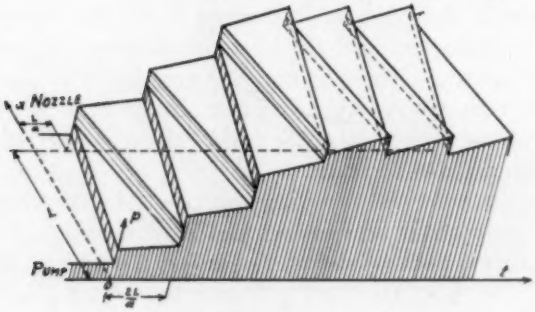


FIG. 8d.

Pump and pipe; variable plunger-velocity: (*a*) history diagram; (*b*) $v-p$ diagram; (*c*) velocity stereogram; (*d*) pressure stereogram.

the influx velocity the smaller are the heights of the individual steps.

The history chart (t–x chart) is divided into zones *I*, *II*, *III*, etc., by the disturbance lines representing the originated and reflected waves. In each zone the velocity and the pressure are constant (or, more correctly, do not undergo a sudden change) as designated by the point bearing the corresponding numerals *I*, *II*, *III*, etc., in the v–p diagram.

The stereograms of velocity and pressure constructed from these data are shown in Figs. 7*c*, *d* in axonometric representation. From these it is easy to visualize the time-history of velocity and of pressure at a given point x in the pipe by forming the intersection of these stereograms by the x = const. plane. In a similar manner the intersections with a t = const. plane give the change of velocity and of pressure along the whole pipe at a certain instant. These stereograms clearly illustrate that during the process of charging the pipe the liquid particles at the pump-end of the pipe move with the uniform velocity v_P, while those adjacent to the closed pipe-end N move with zero velocity. The motion of a particle located between these extreme positions is intermittent, as can be readily visualized from the stereogram.

The case (*b*) involving variable plunger velocity is represented in Figs. 8*a*–*d*, the duration of the pump delivery being $6(L/a)$. The constructions are similar to those employed in the previous case. However, owing to the continuous change of plunger velocity during the first two intervals the condition at the plunger-end of the pipe will be characterized in the v–p diagram (Fig. 8*b*) not by a point, but by the line *II*. To each point in the zone *II* of the time-diagram corresponds a point on the *II* line in the v–p diagram.

When this wave is reflected at the closed end of the pipe the velocity of the layer adjacent to the closed end is reduced to o and the pressure will be defined by the portion of the p axis at *III* in the v–p diagram. In the zone *III* both the pressure and velocity vary along the pipe from point to point and vary also in time from instant to instant. To each point in the zone *III* as defined by the location in the pipe and by the instant of time corresponds in the shaded area *III* in the v–p diagram a point defining the pressure and velocity.

Within each zone the changes of velocity and of pressure are continuous; between the zones the changes are discontinuous.

In this manner the condition of the liquid proceeds from state to state, *IV*, *V*, *VI* and *VII*; in each zone the velocities and pressures are characterized by the points in the corresponding shaded area in the v–p diagram. After the process of inflow is ended the liquid comes to rest only at the layers adjoining the two ends, which are themselves rigid and at rest. In between there exists a surge in forward and backward directions, accompanied by changing pressures and velocities as is clearly shown in the stereograms of velocity and of pressure (Figs. 8*c*, *d*).

FIG. 9*a*.

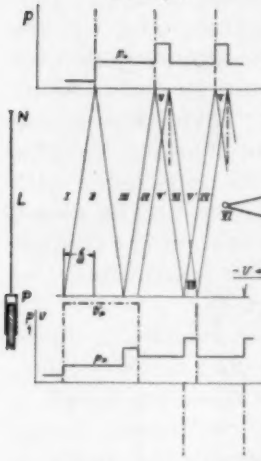


FIG. 9*b*.

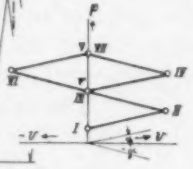


FIG. 9*c*.

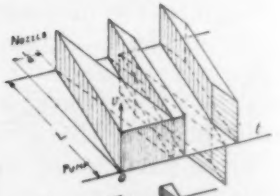
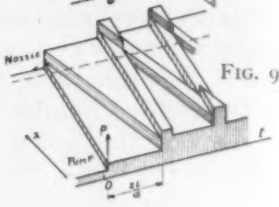


FIG. 9*d*.



Pump and pipe; constant plunger-velocity; charging during fractional intervals: (*a*) history diagram; (*b*) v–p diagram; (*c*) velocity stereogram; (*d*) pressure stereogram.

The case (*c*) involving fractional intervals of pump delivery is represented in Figs. 9*a*–*d*, the duration of delivery being $2, 5(L/a)$. The construction is similar to that shown in the previous examples. At the termination of the pump-delivery the velocity v_P at the pump-end is reduced to zero and the state of flow changes (in the v–p diagram) from point *IV* to point *V'*, which latter is identical to *III*. At the nozzle-end the wave is reflected and a change from *IV* to *V* takes place. The two series of disturbance lines—the one

starting from the $2(L/a)$ instant and the other from the $2, 5(L/a)$ instant—divide the t–x field not into triangular zones as in the former cases, two triangular and another rhomboidal shaped zones as shown in Fig. 9*a*. In each of these zones the velocity and pressure are designated by the correspondingly marked points in the v–p diagram. At the pump-end of the pipe the flow passes through the states *IV*, *V'*, *VI*, *VII*, *IV* and so on; at the closed end the flow passes through the same states but with a phase delay: *VI*, *VII*, *IV*,

FIG. 10*a*.

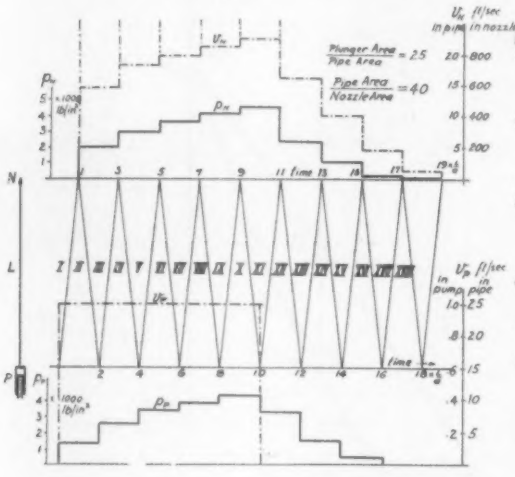


FIG. 10*b*.

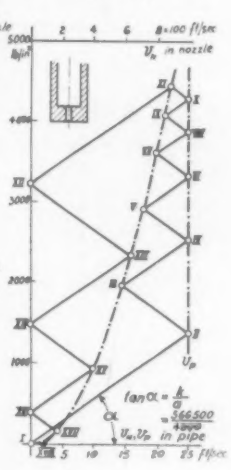
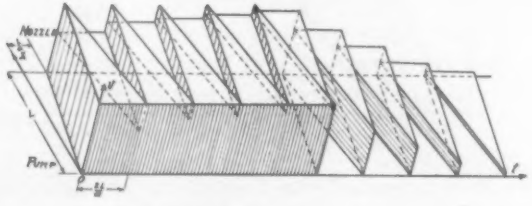


FIG. 10*c*.



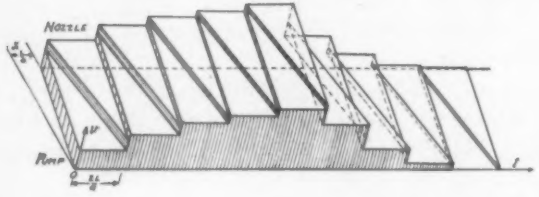
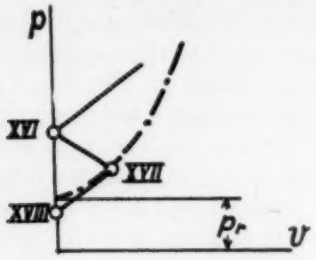


FIG. 10*d*.

FIG. 10e.



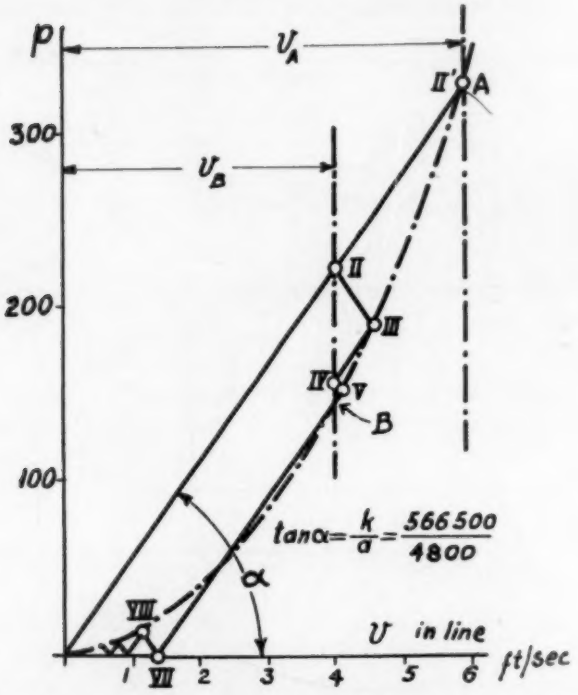


FIG. 10f.

Pump, pipe and open nozzle: (*a*) history diagram; (*b*) v–p diagram; (*c*) velocity stereogram; (*d*) pressure stereogram; (*e*) v–p diagram with back pressure on nozzle; (*f*) v–p diagram of particular cases.

(Note: Correct the value $\tan\alpha = \frac{k}{a} = \frac{266500}{4800}$.)

V', *VI*, and so on. The stereograms of velocity and pressure (Figs. 9*c*, *d*) which are composed from the data in Figs. 9*a*, *b help* to form a clear mental picture of these changing flow-states.

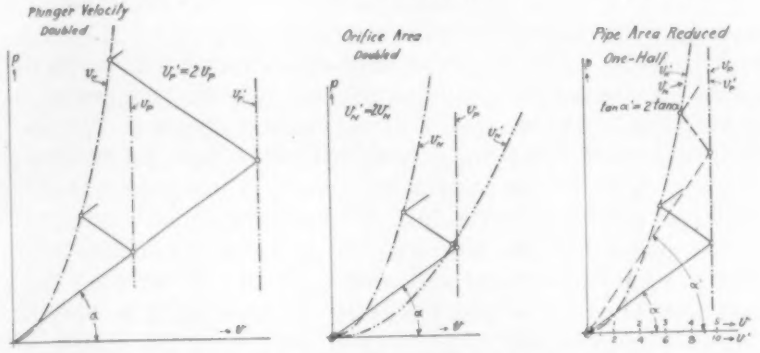
Having now shown how to apply the method to variable velocity and to fractional intervals we shall in the succeeding examples always assume—for simplicity's sake—in each zone a constant velocity and pressure of flow, and disturbances having a duration of even multiple of the L/a interval.

2. Pump, Pipe and Nozzle (Figs. 10*a–d*, 11*a–c*).

It will be assumed that the plunger velocity is constant during the period of pump delivery which lasts during an even multiple of the L/a interval.

The nozzle will be defined by its "efflux characteristic" which is a curve in the v–p diagram showing the velocity of

FIG. 11*a*. FIG. 11*b*. FIG. 11*c*.



Pump, pipe and open nozzle; effect of modifications: (*a*) plunger-velocity doubled; (*b*) orifice-area doubled; (*c*) pipe area halved.

outflow in the pipe at the nozzle-end as a function of the pressure. The characteristic, therefore, involves the dimensions of both the nozzle and of the pipe, and also the back pressure, if any, against which the outflow takes place.

We shall consider three types of nozzles: (*a*) open nozzle, (*b*) closed nozzle with spring-loaded poppet valve, and (*c*) closed nozzle with spring-loaded needle-valve.

(*a*) An *open nozzle* has constant area and the efflux is proportional to the square root of pressure difference:

$$v_N = \frac{\text{Effective Nozzle Area}}{\text{Pipe Area}} \cdot \sqrt{2(p_N - p_R)\frac{g}{w}}, \qquad (15)$$

where w = weight of unit volume of liquid, and p_R = back pressure.

An actual example is worked out in Figs. 10*a–d*, in which the pump delivery is assumed to last ten intervals at $v_P = 25$ ft. sec.$^{-1}$ in the pipe. With a pipe area/nozzle area ratio of 40, and assuming zero back pressure, the efflux characteristic is a parabola as plotted in the v–p diagram. The slope of the directrix: $\tan \alpha = k/a$ is also plotted in the chart.

At the beginning of pump delivery the velocity of the liquid is brought up to the value v_P from its initial state $v = 0$, $p = 0$. This is accompanied by a change of pressure to p_2 as determined by point *II* in the v–p diagram. The condition *II* will exist in the zone *II* of the v–p diagram. This point does not lie on the efflux characteristic, the velocity being greater than the efflux corresponding to p_2 pressure. Therefore the arriving wave is decelerated and its pressure is increased till condition v_3p_3 characterized by point *III* in the v–p diagram, located on the efflux parabola. This reflected wave, on reaching the pump plunger, is again brought up to the velocity v_P at the point *IV* in the v–p diagram. Following this procedure we obtain points *V*, *VI*, · · · *XI* in the v–p diagram defining the state of flow in the zones designated by the same numerals in the history chart, Fig. 10*a*.

At the end of the 10th interval the pump delivery ceases and the velocity of the reflected wave *XI* is reduced to 0, corresponding to the point *XII* in the v–p diagram. As the liquid column is still under pressure, efflux at the nozzle will take place at the cost of pressure, according to point *XIII*. Continuing this procedure, we obtain in the v–p diagram the points *XIV*, *XV*, · · · *XVIII*, each point defining the v and p values existing in the zones marked by the same numerals in the time diagram. In the zone *XVIII* the pressure becomes zero, but there is still velocity. Therefore, when the wave reaches the pump-end of the line the column separates from the plunger. If we still consider the column as coherent and unbroken then the velocity would be reduced and the pressure increased along the directrix until it intersects the efflux parabola and this process would continue until, after an infinite number of small steps, the point of origin would be reached. (It has to be stated, however, that our analysis assumed the continuity of the column and actually the reduction of pressure to zero would involve vapor formation and

liberation of bubbles, to which condition our method of analysis would not apply.)

If we assume that there is, in front of the nozzle a back pressure against which the outflow takes place, then this uncertainty would not arise. The efflux parabola in this case would start from the p_R point and the outflow would definitely end after the reflected wave attains a $p < p_R$ value as shown in Fig. 10*e*.

From the v–p diagram the pressure and corresponding velocity values can be transferred to the t–x diagram, and thus the lines of velocity-history and pressure-history at the pump-end and at the nozzle-end determined. The axonometric picture of the stereograms of velocity and of pressure thus obtained are shown in Figs. 10*c*, *d*.

According to the relative magnitude of the efflux characteristic as compared to the influx characteristic various types of transients are conceivable some of which are shown in Fig. 10*f* (in the v–p diagram only because the transcription into the time diagram is not necessary for the understanding).

If the velocity of pump delivery v_B is such that point *II* lies below the efflux parabola, then the wave, on arriving at the nozzle, loses some of its pressure and gains in velocity until a point *III* on the efflux line is attained, and after a number of reflections a position of equilibrium is reached at the point of intersection B of the v_B = const. line with the efflux parabola. After the pump delivery has ended the pressure and velocity fall in steps according to points lying alternately on the efflux parabola and on the v axis as shown in the illustration.

In the particular case when the point *II* lies on the efflux parabola, at point A the pressure and velocity are just correct for the outflow and no wave is reflected from the nozzle. The outflow assumes the state of steady flow v and p remaining constant during the injection. After the delivery ceases the outflow is stopped too and the state of the liquid assumes the initial conditions ($v = 0$, $p = 0$). In this case:

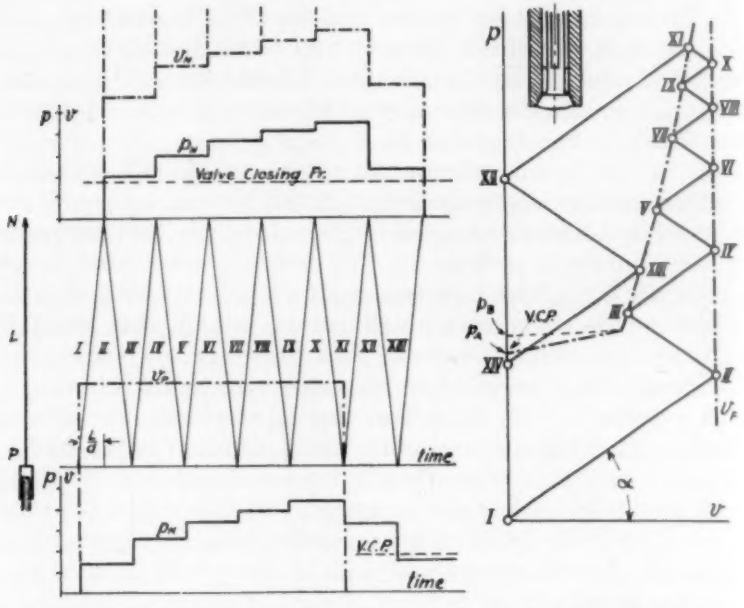
$$\left(\frac{F}{f}\right)^2 v^2 = 2p\frac{a^2}{k}; \quad \frac{F}{f} = \frac{\text{pipe area}}{\text{nozzle area}}; \quad v = 2a\left(\frac{f}{F}\right)^2, \qquad (16)$$

which is the criterion for no reflection.

On Figs. 11*a–c* are shown the effects of various modifications of a system comprising Pump, Pipe and Open Nozzle which are of interest for Diesel fuel injection.

1. What is the effect if the plunger speed is doubled (trebled or quadrupled)? In the *v–p* diagram this change is represented by drawing the v_P line at double of the original distance from the origin (Fig. 11*a*). It is seen that the flow

FIG. 12*a*. FIG. 12*b*.



Pump, pipe and closed nozzle (poppet-valve type): (*a*) history diagram; (*b*) *v–p* diagram.

velocity in the pipe at the nozzle-end will be less than doubled (trebled or quadrupled).

2. What is the effect if the area of the nozzle orifice is doubled (trebled or quadrupled)? In the *v–p* diagram this change can be represented by drawing the efflux parabola with the *v* abscissas doubled (Fig. 11*b*). It is seen that the flow velocity in the pipe at the nozzle-end will be less than doubled (trebled or quadrupled).

3. What is the effect if the cross-sectional area of the pipe is reduced to ½ (⅓ or ¼) of its original value? In the *v–p*

diagram (Fig. 11*c*) this change can be represented by correspondingly reducing the velocity scale (e.g., if originally 10 ft./sec. was represented by 1″ then with the halved pipe area 10 ft./sec. will be represented by ½″), and correspondingly double the direction tangent: $\tan \alpha' = 2 \tan \alpha$. It will be seen that the flow velocity in the pipe at the pump-end will be doubled, and at the nozzle-end more than doubled.

4. What is the effect if the length of pipe is altered to ½ (⅓ or ¼) of its original value? In that case the time-interval

FIG. 13*a*.

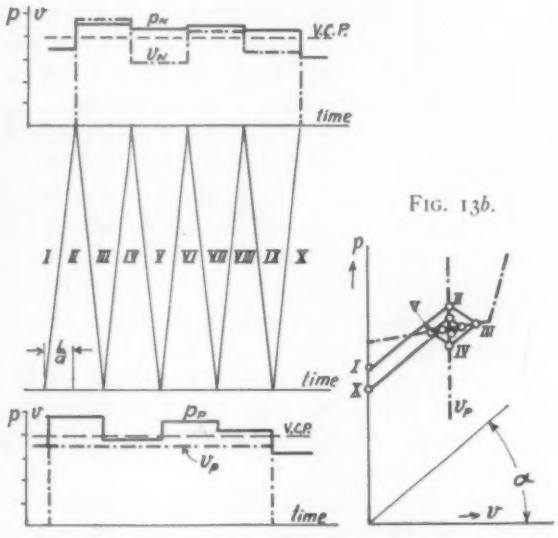


FIG. 13*b*.

Pump, pipe and closed nozzle (poppet-valve type); fluctuating discharge: (*a*) history diagram; (*b*) $v-p$ diagram.

L/a of a single traverse is reduced to ½ (⅓ or ¼) of its original value. Therefore in a given time there will be twice (three or four times) as many surges and the time-history of discharge will resemble more closely the time-history of pump delivery.

(*b*) *Pump, Pipe and Spring-Loaded Poppet Valve* (Figs. 12*a*, *b*, 13*a*, *b*). The poppet valve opens outwards, is spring-loaded with an initial tension and its travel is limited by a stop. Therefore a certain minimum pressure p_A is needed to

crack the valve open and another $p_B > p_A$ to bring it to its fully open position. With pressures greater than p_B the nozzle acts as an open nozzle. The efflux characteristic is represented, therefore, by a parabola, the apex of which is truncated by a sloping line as shown in Fig. 12*b*.

Again assuming a pump delivery at constant v_P during ten intervals the v–p diagram can be drawn as shown in Fig. 12*b*, starting from point *I* and then continuing in steps designated by points *II*, *III*, $\cdots$ *X*, *XI* during the pump delivery. On the termination of pump delivery the velocity of the returning wave *XI* is reduced to zero and point *XII* is attained. As the liquid pressure is still greater than the valve opening pressure p_A further outflow takes place according to condition *XIII*. On being reflected from the nozzle the wave reaches the pump-end with a pressure $p_{14} < p_A$ when the valve closes and no further outflow takes place.

The pressures and velocities defined by points *I*, *II*, $\cdots$ *XIV* in the v–p diagram have been transcribed into the time-diagram and thus the history of pressure and of velocity at pump-end and at nozzle-end plotted as shown in Fig. 12*a*.

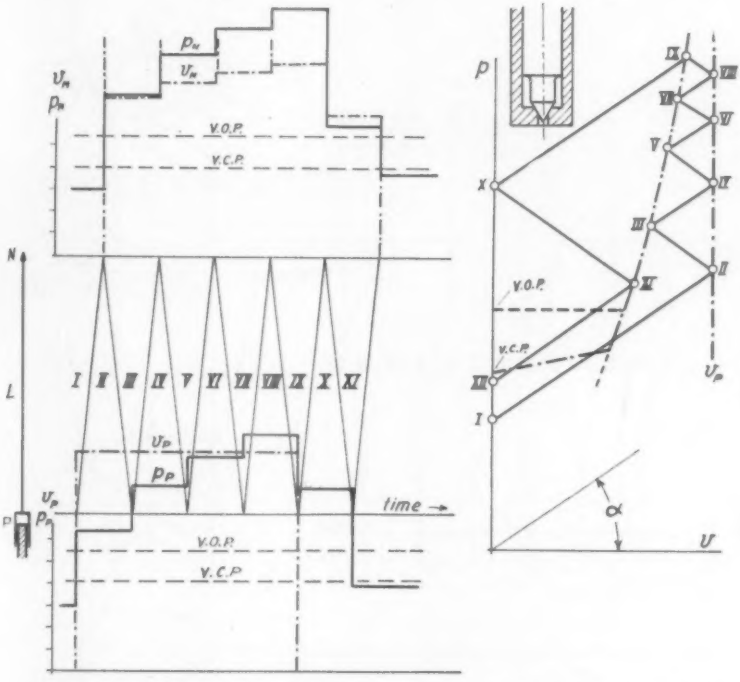
On inspection of this diagram it is evident that the initial pressure in the pipe is not necessarily equal to the final pressure in the pipe; nor is the final pressure equal to the valve opening pressure but can be less than that within certain limits. From this it follows that in general the consecutive injections will not be identical with each other as regards the rate and pressure of injection.

A particular case is illustrated in Figs. 13*a*, *b*. If the relationship of pump delivery and efflux characteristic is such that their intersection lies on the rapidly rising, approximately straight line portion of the efflux line (while the valve is not yet fully opened), then the outflow will be fluctuating in each double interval according to the v_N line in the time-diagram of the Fig. 13*a*. Also in this case the final pressure is not necessarily the same as the initial pressure.

(*c*) *Pump, Pipe and Spring-Loaded Needle-Valve* (Figs. 14*a*, *b*, 15*a*–*c*). This type of nozzle is characterized by the valve-opening pressure (V.O.P.) being greater than the valve-closing pressure (V.C.P.). This is due to the difference of the cross-sectional areas of the needle-valve which is exposed

to the fluid pressure when the valve is closed as compared with the opened condition, i.e., greater fluid pressure is needed to open up the nozzle than to keep it open. This feature is expressed in the efflux characteristic by two truncating lines adjoining to the parabola as shown in Fig. 14*b* and attention has to be given to use the one originating from the V.O.P. when the nozzle is not open yet, and use the other, originating

FIG. 14*a*. FIG. 14*b*.



Pump, pipe and closed nozzle (needle-valve type): (*a*) history diagram; (*b*) v–p diagram.

from the V.C.P., when the nozzle is already open. In our present analysis we shall neglect the mass and inertia of the needle valve.

The construction is similar to that in the foregoing example and does not need further explanation.

Particular cases arise if the influx velocity is low (Figs. 15*a*, *b*). Starting from state *I* the velocity is raised by the

plunger to v_P corresponding to point *II* in which the pressure is less than the V.O.P., therefore the column comes to rest (Point *III*) and the pressure is increased but not sufficiently to open the valve. The plunger imparts again a velocity v to the column (Point *IV*) which has now a pressure greater than V.O.P.; the valve is opened and efflux takes place with

FIG. 15a. FIG. 15b.

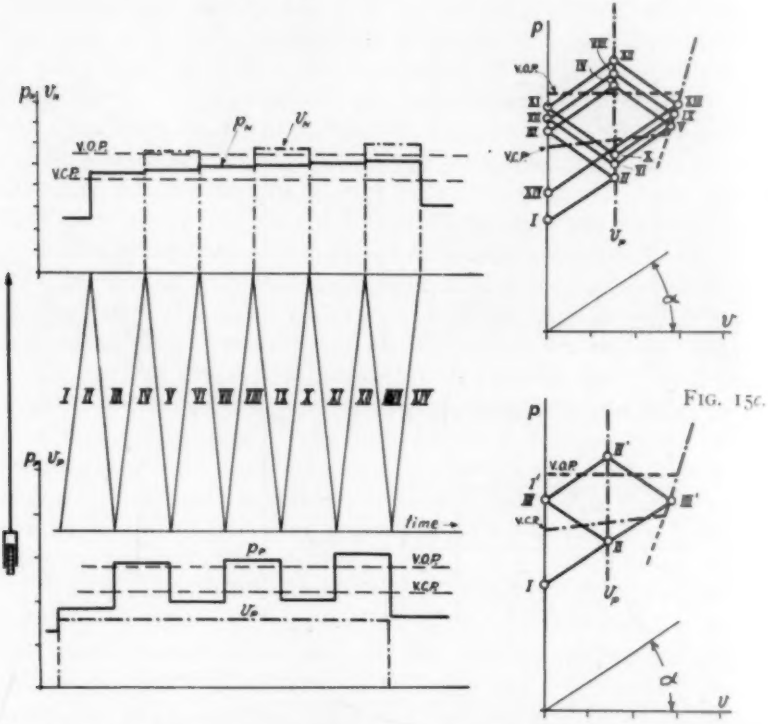


FIG. 15c.

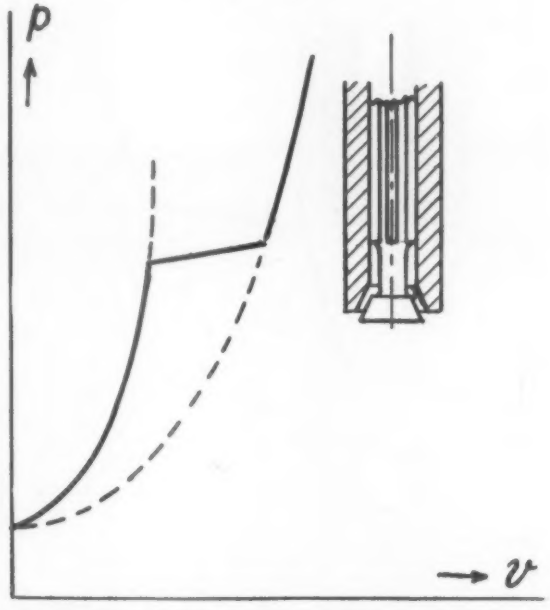
Pump, pipe and closed nozzle (needle-valve type); fluctuating discharge: (*a*) history diagram; (*b*) $v-p$ diagram; (*c*) $v-p$ diagram of double-stroking.

a velocity and pressure *V* located on the efflux curve. On reaching the pump-end the state *VI* is attained, the pressure of which is lower than the V.C.P.; therefore, when this wave reaches the nozzle-end the valve closes (*VII*) and the column is brought to rest. This alternate opening and closing of the valve continues until, at the end of interval *XII*, the pump

delivery ceases (*XIII*) and the column comes to rest in the state *XIV*.

If, in addition to the influx velocity v_P being low, also the duration is short then the phenomenon known as "double stroking" will occur, i.e., the injection will take place at every alternate pump delivery period. The v–p diagram of this phenomenon is shown in Fig. 15*c*, in which it is assumed that the total duration of delivery is $2(L/a)$, i.e., a double interval

FIG. 16*a*.



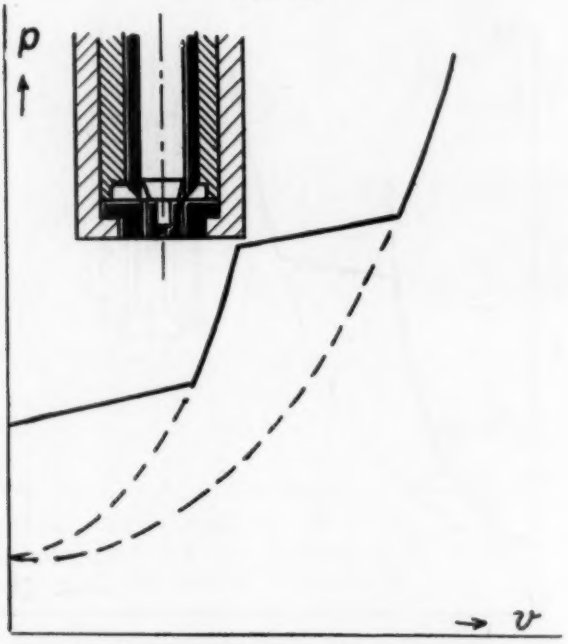
Efflux characteristic of nozzle with poppet-valve and initial opening.

of traverse. The first wave originating at the pump (Point *II*) has not enough pressure to open the valve; therefore, the column comes to a standstill (Point *III*) with a pressure still less than the V.O.P. The pipe line, however, will remain filled with liquid under p_3 pressure and the next delivery starts from this point *I'*. The pressure of this wave (*II'*) is already greater than the V.O.P. and injection takes place (Point *III'*). After the pump delivery is over the liquid assumes again the original state *I*.

(*d*) *Other Types of Nozzles* (Figs. 16*a*, *b*). While the three types of nozzles treated in the foregoing are of the most practical importance, yet other types of nozzles are conceivable and even may be practicable.

A poppet-valve type of nozzle may have an initial opening (e.g., the nozzle used in the Packard Aircraft engine). The efflux characteristic of such a nozzle would be (qualitatively) similar to Fig. 16*a*.

FIG. 16*b*.



Efflux characteristic of nozzle with double needle-valve.

Another type of nozzle is the one used by the National Advisory Committee for Aeronautics (Spanogle and Whitney: The Effectiveness of a Double-Stem Injection Valve in Controlling Combustion in a Compression-Ignition Engine. N. A. C. A., T.N. 402, 1931) in which two concentric valves are used, each valve being loaded separately by springs, and open successively. The efflux-characteristic of such a nozzle would be similar to Fig. 16*b*.

3. Pump and Storer (Figs. 17*a*, *b*, 18*a*, *b*).

In the v–p diagram (Fig. 17*b*) the initial condition is represented by point I (p_1, $v_1 = 0$) and the plunger velocity by

FIG. 17*a*.

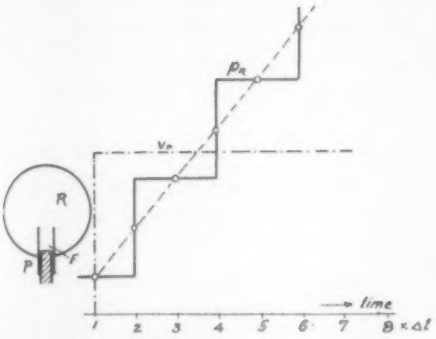
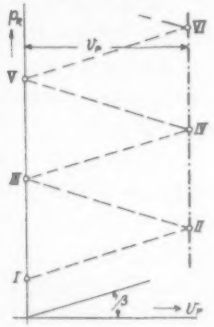


FIG. 17*b*.



Pump and storer: (*a*) history diagram; (*b*) v–p diagram.

FIG. 18*a*.

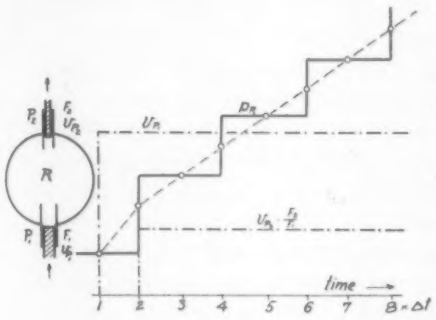
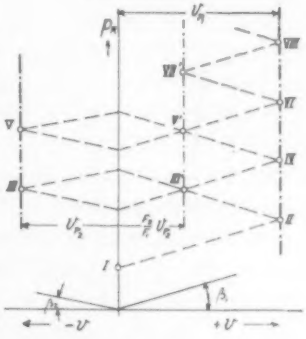


FIG. 18*b*.



Two pumps and storer: (*a*) history diagram; (*b*) v–p diagram.

the v_P = const. line. The pressure change during an arbitrarily chosen small time interval Δt will be (from Eq. 12):

$$p_2 - p_1 = k\frac{v_P F \Delta t}{R} = v_P \tan \beta$$

as long as the plunger-velocity v_P prevails. Determining the direction-tangent,

$$\tan \beta = \frac{kF\Delta t}{R},$$

the points *II*, *III*, *IV*, *V* ⋯ can be obtained in the v–p diagram and the corresponding p values transferred into the history-diagram (Fig. 17*a*) showing a stepped line. Choosing the Δt interval smaller and smaller diminishes in direct ratio the value of $\tan \beta$, decreases the height and increases the number of steps during a given time. As Δt approaches zero the discontinuous stepped line of p will approach the true continuously changing sloping line shown dotted in the diagram.

If there are two or more pumps attached to the same storer the sum or difference—as the case may be—of the deliveries of the several individual pumps has to be used as the basis of construction. In the example shown in Figs. 18*a*, *b* two pumps P_1 (plunger area F_1, plunger velocity v_{P_1} and direction tangent $(kF_1\Delta t/R) = \tan \beta_1$) and P_2 (with corresponding values F_2, v_{P_2} and $(kF_1\Delta t/R) = \tan \beta_2$) are assumed, P_1 feeding into and P_2 withdrawing liquid from the storer. In the v–p diagram, therefore, the v_{P_1} line has to be drawn on the positive side, the v_{P_2} on the negative side of the point of origin *O*. Starting in the v–p diagram from the initial condition *I*, after the first interval of feeding in by the pump P_1 the condition *II* is attained. After the second interval, assuming for the moment no withdrawal by the pump P_2, the condition III_a would be obtained. Actually during the second interval the pump withdraws some liquid, but as we are dealing with small time-intervals it is permissible to base our graphical construction on the assumption that the withdrawal takes place consecutively instead of—as it actually occurs—simultaneously. This is a fruitful assumption of which use will be made also in other problems to be treated later. Continuing from point III_a the withdrawal by the pump P_2 during the second interval Δt diminishes the pressure to *III* and after the third interval the pump P_1 brings up the pressure to III_b. This construction is continued as long as the plunger velocities v_{P_1} and v_{P_2} prevail and thus the points *V* and *VI* are obtained.

The construction can be simplified by reducing all pump characteristics to the same plunger area, say to that of F_1. Doing this we shall deal with the pump characteristics v_{P_1}; $(F_2/F_1)v_{P_2}$; $(F_3/F_1)v_{P_3}$ and so on, and the same $\beta = \beta_1$ will apply to all. It is clearly visible that in our case we thus

obtain more simply the points *III'*, *V'*, *VII'* ··· and so on, which have the same pressure values as *III*, *V*, *VII* and so on, obtained by our original method in a more complicated manner. Similarly to the former case as the Δt interval is made to approach zero the stepped, discontinuous p_R line will approach the continuous sloping line shown dotted in the diagram.

(To be continued)

Chilling Wheat Blooms Makes Crossing Easier.—Severe chilling of wheat plants—either by natural frost or by artificial refrigeration—is a promising new tool for plant breeders who are working to develop new varieties of wheat with special qualities such as drought resistance, winter hardiness or disease immunity. COIT A. SUNESON of the Bureau of Plant Industry, U. S. Dept. of Agriculture, has announced results of experiments in which by chilling them he emasculates the heads of the wheat plants, killing the pollen and thus preventing the normal self-fertilization of the wheat florets, and at the same time opening up the head so that it was easy to apply pollen collected from another variety of wheat. Working at Lincoln, Nebraska, Mr. Suneson brought the wheat plants to the stage where heads were forming but had not emerged from the protective sheath. At this stage temperatures of 27 to 32 deg. F. killed the pollen but did not kill the pistillate parts of the flowers, and as the heads emerged from the sheath the protecting tissues were left open. Thus it was easy to dust the emasculated head with foreign pollen and so make a quick and easy crossing. By making crosses in this relatively quick and easy way, it may be possible, says the Bureau, to make more rapid progress in developing new wheat varieties with specific desirable qualities. By making many crosses and selecting desirable plants from the offspring, the breeder would improve his chances of getting just the desired combination promptly. At best, plant breeders explain, the search for new hybrids is something of a gamble in that large numbers may be required to get the desired combination through the operation of chance alone. Any device that will improve the odds and allow the breeder wider choice from the same skill and effort is a tool that is likely to prove valuable.

R. H. O.

A TERRESTRIAL ORIGIN FOR COSMIC RAYS.

BY

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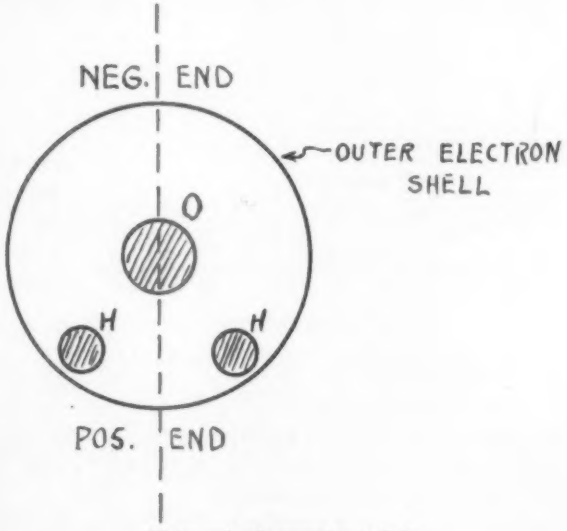
Debye's picture of the polar water molecule, with its strong permanent electric moment, and its unsymmetrical arrangement of mass points all lying inside the outer electron shell of the oxygen atom offers some interesting possibilities when considered under the influence of the earth's gravitational field.

According to Debye [1] the mass points of the water molecule are as shown in Fig. 1, with the two hydrogen nuclei

FIG. 1.



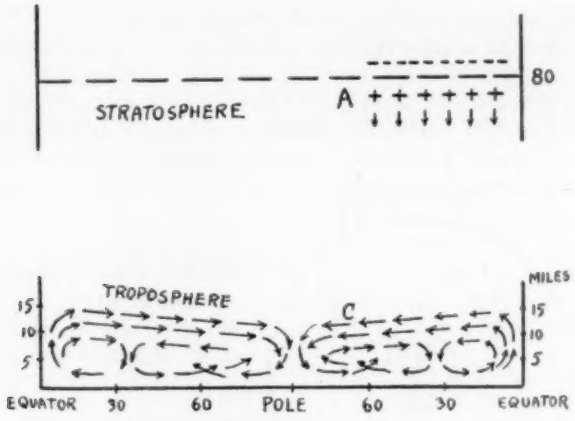
Water molecule according to Debye.

just inside the outer shell of electrons. Under the action of gravitational forces there would be a tendency for such a

[1] Debye, P., "Polar Molecules," Chem. Cat. Co., N. Y., 1929.

molecule to assume the position shown, with the heavy end turned downward. But the water molecule also has a strong permanent electric moment of 1.85×10^{-18} e.s.u. Such an orientation of water molecules, therefore, with the positive ends down and negative ends up, would result in a negative charge of electricity all over the surface of the earth, except in the frozen polar regions where the molecules would be incapable of turning. Such a condition, combined with the ionization of the upper atmosphere by ultra-violet radiations from the sun, and the circulation of the earth's atmosphere, is sufficient to account for the existence and maintenance of the earth's electric gradient. The process may be pictured as follows. Fig. 2 shows the general circulation of the earth's

FIG. 2.



General planetary circulation.

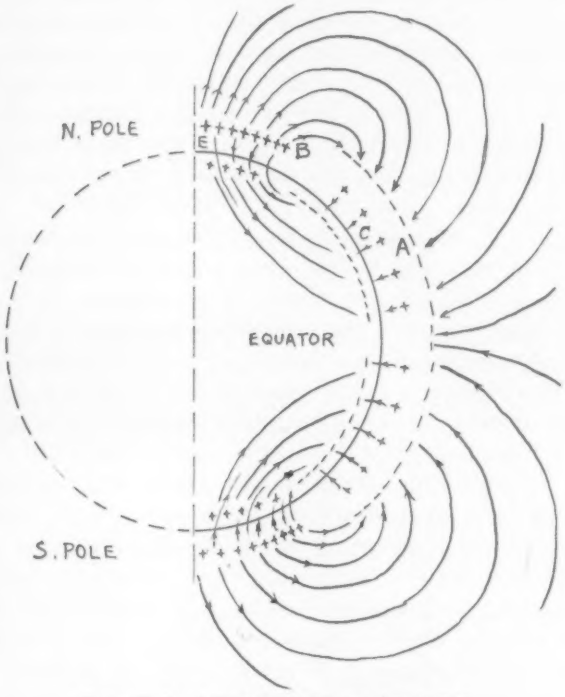
atmosphere with respect to height.[2] Under the action of the earth's electric gradient positive and negative ions created in the stratosphere by the sun's ionizing radiations (at heights of from 75 to 100 miles)[3] will be separated, the positive charges moving downward as shown at *A*, Fig. 2. Positive charges reaching the region marked *C* in Fig. 2 will be swept toward the polar regions by the strong poleward winds

[2] See for example Ridgley, D. C., and Koeppe, C. E., "Weather and Climate," McKnight and McKnight, Bloomington, Ill., 1930, p. 49.

[3] For a résumé of existing knowledge of the Ionosphere see Hund, A., "Phenomena in High Frequency Systems," McGraw-Hill, 1936, p. 388.

existing at heights of 10 to 15 miles. This will result in an accumulation of positive charges at both poles. The earth's electric field then would be as pictured in Fig. 3. "*A*" in

FIG. 3.



Cross-section through earth showing electric field.

this figure represents the region where the ions are being produced. Any positive ions succeeding in reaching the earth would be neutralized by the free electrons there. The neutral air molecules would then be free to return to the upper air to repeat the process. This would result in a continuous withdrawal of electrons, part of which would come from the polar regions resulting in a further intensification of the positive concentration there.

The field in the region marked *C* is known to exist, with a mean value of about 150 volts per meter.[4] The intense

[4] See for example the article by Swann, W. F. G., in *Encyc. Brit.* under "Atmospheric Electricity."

field to be expected at *B* is evidenced by the auroral phenomena observed at heights of 65 to 400 kilometers. The falling off of the field intensity in the upper region *A* has also been observed. The field in the polar regions marked *E* might be positive or negative depending upon the relative amounts of positive charges above and below the observer at the particular time of observation. Reports of reversal of gradient are common for both poles (see for example the reports on the Maude Polar Expedition or the British Antarctic Expedition Reports). It does not seem unreasonable therefore to suppose that the outer field marked *F* also exists. In fact, it would *have* to exist if the others did. Further evidence of its existence is also furnished by the emission spectrum of the night sky, which is undoubtedly due to ionization by collision processes going on in the upper regions where the free paths of the molecules are long.

The important point, however, is that for a mean gradient of only 100 volts per meter, such a field would need to exist in an arc of only 10,000 kilometers length to amount to the 10^9 volts required to account for the production of cosmic rays. The intensity distribution of cosmic ray particles (with respect to latitude) produced by such a field would also coincide with the observed intensity distribution, which is known at present as the cosmic ray "magnetic effect" and which is supposed to be due to a deflection of incoming particles by the earth's magnetic field. (See summary by Hull mentioned above.) Positive ions accelerated by the field at the poles would emerge from the polar regions and spray down all over the temperate and equatorial regions, and should therefore be few and hard in those regions as observed. At the same time negative particles starting from the upper levels of the temperate and equatorial regions would return to the poles where they would all be concentrated. They therefore should be plentiful and soft. This has also been observed.

To summarize, the proposed mechanism consists of two parts: first, the vertical separation of positive and negative ions by the earth's electrical gradient (the downcoming cloud of positive ions is a well established fact); second, an additional horizontal separation by the poleward air currents. To

account for "cosmic" radiations by means of the simple terrestrial mechanism pictured above seems eminently more satisfactory and reasonable than to imagine them to originate everywhere in general and nowhere in particular, as at present.

Exact calculations of course are impossible at this stage. The following computations, however, will suffice to indicate that such a state of affairs is not at all unreasonable. Taking an average of 100 volts per meter, the energy in the known field of the earth gradient is roughly

$$\frac{E^2}{8\pi} = \frac{1}{8\pi}\left(\frac{100}{300 \times 100}\right)^2 = 4 \times 10^{-7} \text{ ergs per cm.}^3.$$

Assuming a height of 10 kilometers this would amount to 2×10^{18} ergs for the entire electrical energy represented in the vertical electric gradient of the troposphere. The total amount of potential energy represented by the lowering of the heavy ends of the water molecules, and available for the initial vertical separation of the ions, would be

$$Nmgh = 3.4 \times 10^{22} \times 3.3 \times 10^{-24} \times 10^3 \times 10^{-8} = 10^{-6} \text{ ergs per cm.}^3.$$

For an average depth of water of 12,000 feet this would amount to a total of 2×10^{18} ergs. The two are thus seen to agree in order of magnitude.

Next, for the energy involved in the horizontal separation of charges, if one assumes the upper field F to have the same average energy density, 4×10^{-7} ergs per cm.^{3}, as the lower field, and, as an upper limit, 100 times the *extent* of the lower field, the energy would amount to a total of $100 \times 2 \times 10^{18}$ or 2×10^{20} ergs for the upper field. Next, taking the atmospheric current of air in the upper troposphere as the horizontal separating agency, the total energy available could be estimated roughly as follows. Wind velocities near the top of the troposphere are reported as high as 30 meters per second. Taking as an average value 10 meters per second, the kinetic energy per cubic centimeter of air would be

$$\tfrac{1}{2}Nmv^2 = \tfrac{1}{2}(.0004)(10 \times 100)^2 = 2 \times 10^2 \text{ ergs per cm.}^3.$$

Then if we assume an average thickness for the poleward current of air to be only 2 kilometers, this would give a total

energy of 2×10^{26} ergs. But such a value is a million times more than the required amount, 2×10^{20}. Thus we conclude that the energy required for the horizontal separation which produces the outer field F needed to account for cosmic ray energies is ample by a margin of more than one million times. This margin is even greater when one considers that 2×10^{20} is the *existing* energy of the field but that the wind needs to to supply only enough energy to *maintain* it, not to create it.

In concluding, it is difficult to resist the temptation to speculate on the possibilities resulting if we imagine similar electric fields to exist on other planets. For example, the anomalous temperature-radiation condition of Jupiter could be explained by assuming that its atmosphere is continually ionized by the fields to be expected on such a huge planet, without the hypothesis of internal supplies of heat. Such a phenomenon would also account for the mysterious red, orange and blue banded appearance of Jupiter. Again, for Saturn the rings could be accounted for by the presence of ionized gas molecules held in a state of balance between the opposing forces due to the inward gravitational field and the outward electrical field around the equator, one ring for each kind of gas molecule present. A similar state would be sufficient to account for the zodiacal light of the earth with its accompanying phenomenon the gegenschein or "counter-glow"; that is, by electrified particles carried far out into space at the earth's equator by the electrical field there. The glow would be due to sunlight reflected from such particles. Also, it is interesting to speculate on the possible association of similar forces with the origin and evolution of the solar system. As a planet cools and the thermal agitations of its molecules decreases the electrical forces should increase to a maximum and then decrease again as the molecules freeze. This suggests, in turn, the possibility of the lunar craters having been caused by successive rings thrown off from earth during the period in which its electrical field was increasing. The list of possibilities opened up by such planetary fields and their consequent radiations is thus seen to be endless.

ON A FORMULA OF RAYLEIGH FOR VELOCITY POTENTIAL.

BY

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London.

1. In a paper entitled "An Operational Proof of the Wave-Potential Theorem with Applications to Electromagnetic and Acoustic Systems," which was published in the JOURNAL OF THE FRANKLIN INSTITUTE, **221**, 484, 1936, Stuart Ballantine made the following remarks: "The formula (44) [namely

$$\phi = -\frac{1}{2\pi}\int\int \frac{\partial\phi}{\partial n}\cdot\frac{e^{-ikr}}{r}\,ds$$

due to Rayleigh] is also extensively used to calculate the radiation from a piston (rigid disk) in an infinite baffle. Here we are faced with the same type of difficulty. We know $-(\partial\phi/\partial n)$ (the velocity normal to the surface) over the face of the vibrating surface and the baffle, but do not know what ϕ is. The customary use of (44) of the text books is, therefore, improper in this case also."

When a body vibrates in a fluid medium in which the motion is irrotational and there are no normal modes of vibration of the fluid occupying the region,[1] two well-known conditions have to be fulfilled: (1) The velocity potential must everywhere satisfy the equation

$$(\nabla^2 + k^2)\phi = 0, \qquad (1)$$

where $\nabla^2 = (\partial^2/\partial x^2) + (\partial^2/\partial y^2) + (\partial^2/\partial z^2)$, $k = \omega/c$, $\omega = 2\pi$ frequency and c = velocity of sound waves in the medium; (2) the prescribed boundary conditions must be satisfied.

The solution of (1) for sinusoidal motion and any boundary condition is [2]

$$\phi_P = -\frac{1}{4\pi}\left[\int\int \frac{\partial\phi_S}{\partial n}\cdot\frac{e^{-ikr}}{r}\,ds - \int\int \phi_S\frac{\partial}{dn}\frac{e^{-ikr}}{r}\,ds\right], \qquad (2)$$

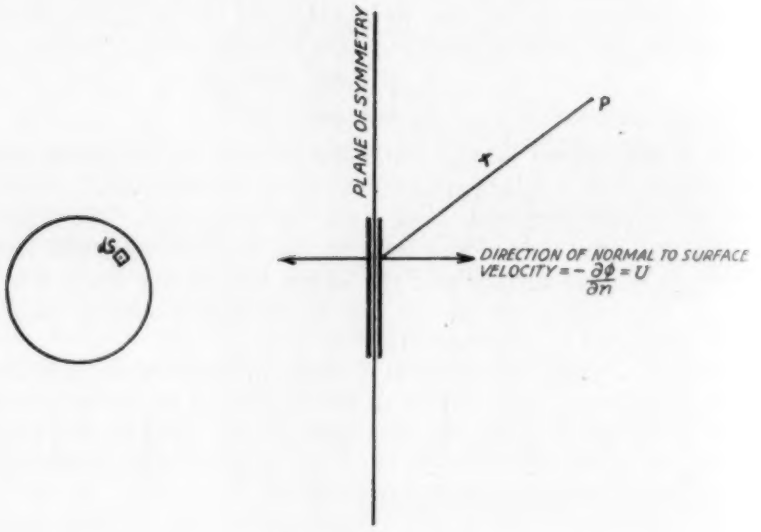
[1] Lamb, "Hydrodynamics," 4th ed. (1916), p. 493. This applies to the disk case treated herein.

[2] Lamb, loc. cit., p. 491.

where the subscripts P and S refer, respectively, to a spatial point and one on the vibrating surface. This is the solution given by Ballantine.

Consider the sound field due to the two outer faces of an extremely thin disk vibrating in opposition,[3] as illustrated in Fig. 1. The air particle velocity normal to the extension of the plane of the disk is zero, whilst the velocity potential at the plane and at any spatial point without it, will not be affected if a rigid infinite baffle were situated in the plane of

FIG. 1.



symmetry. Thus to obtain a formula for the velocity potential on one side of the baffle, we can apply (2) to the two faces of an unbaffled disk, provided the faces vibrate in opposition.

For the first side of the disk we have

$$\phi_1 = \frac{U_1}{4\pi}\int\int \frac{e^{-ikr}}{r}\,ds_1 - \frac{1}{4\pi}\int\int \phi_{s_1}\frac{e^{-ikr}}{r^2}(1 + ikr)\frac{\partial r}{\partial n}\,ds_1; \quad (3)$$

[3] A practical arrangement of this concept is envisaged in British Patents 270,412; 271,021 (1926) and in McLachlan, "Loud Speakers," Clarendon Press, 1934, p. 127.

and for the second side

$$\phi_2 = \frac{U_2}{4\pi}\int\int \frac{e^{-ikr}}{r} ds_2 - \frac{1}{4\pi}\int\int \phi_{s_2} \frac{e^{-ikr}}{r^2}(1 + ikr)\frac{\partial r}{\partial n} ds_2, \quad (4)$$

where $U = U_1 = U_2 = -(\partial\phi/\partial n)$ is the velocity normal to each surface.

The velocity potential at any spatial point P is the sum of (3) and (4). With reference to P, the quantity $\partial r/\partial n$ is equal but of opposite sign at the two faces of the disk, since the direction of the normal is outwards from the surface. Hence the second integrals in (3) and (4) neutralize each other, and we obtain

$$\phi_P = \phi_1 + \phi_2 = \frac{U}{2\pi}\int\int \frac{e^{-ikr}}{r} ds = -\frac{1}{2\pi}\int\int \frac{\partial\phi}{\partial n}\cdot\frac{e^{-ikr}}{r} ds, \quad (5)$$

where the integration now extends over *one* face of the disk. Now (5) is a solution of equation (1), and as we have already shown that the sound field on one side of the plane of symmetry is unaltered if a rigid barrier is interposed, it follows that (5) satisfies the boundary conditions in either case. Hence the validity of formula (5) is confirmed in connection with problems of radiation from a vibrating rigid disk in an infinite baffle.

Although the preceding argument leaves no room for doubt, we give additional proof below. Using cylindrical polar coördinates as illustrated in Fig. 2, the velocity potential distribution is symmetrical about the axis of the disk, so it is independent of θ. Thus equation (1) can be written in the form

$$\frac{\partial^2\phi}{\partial\rho^2} + \frac{1}{\rho}\frac{\partial\phi}{\partial\rho} + \frac{\partial^2\phi}{\partial z^2} + k^2\phi = 0, \quad (6)$$

of which the formal solution is

$$\phi = e^{-z\sqrt{\chi^2-k^2}}[AJ_0(\chi\rho) + BY_0(\chi\rho)], \text{ where } \chi \text{ is arbitrary}, \quad (7)$$

J_0 and Y_0 being Bessel functions of the first and second kinds of zero order. At the centre of the disk where $\rho = 0$, $Y_0(\chi\rho) = \infty$, but as ϕ is finite it follows that $B = 0$. Hence

the required solution is

$$\phi = Ae^{-\lambda z}J_0(\chi\rho), \tag{8}$$

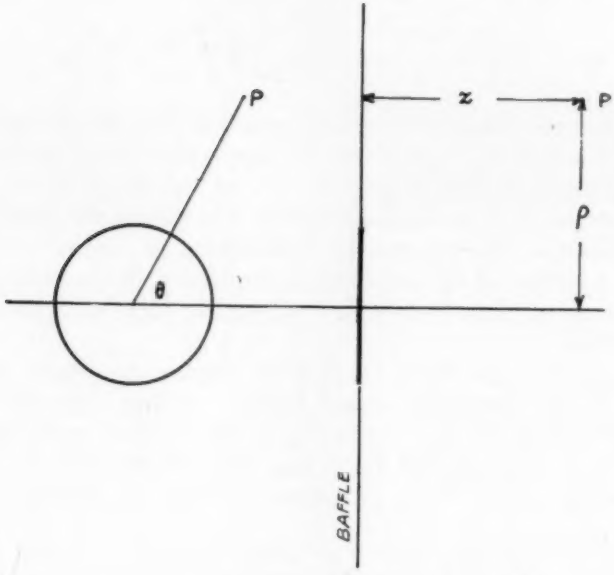
where $\lambda = \sqrt{\chi^2 - k^2}$.

If we write $A = \chi f(\chi)/\lambda$, then it is evident that

$$\phi_P = \int_0^\infty e^{-\lambda z}J_0(\chi\rho)f(\chi)\chi\cdot\frac{d\chi}{\lambda} \tag{9}$$

is also a solution of equation (6). For boundary condi-

Fig. 2.



tions we have $U = -(\partial\phi/\partial z)_{z=0}$ over the disk, but zero over the baffle, so $-(\partial\phi/\partial z)_{z=0} = U$, when $0 < \rho < a$, and $-(\partial\phi/\partial z)_{z=0} = 0$, when $a < \rho < \infty$. Differentiating (9) with respect to z and putting $z = 0$, we get

$$U = -\left(\frac{\partial\phi}{\partial z}\right)_{z=0} = \int_0^\infty J_0(\chi\rho)f.(\chi)\chi d\chi \tag{10}$$

The problem is now to solve this integral equation for $f(\chi)$.

By Hankel's inversion theorem if

$$\xi(\rho) = \int_0^\infty J_n(\chi\rho) f(\chi) \chi d\chi, \tag{11}$$

then

$$f(\chi) = \int_0^\infty J_n(\chi\rho) \xi(\rho) \rho d\rho. \tag{12}$$

Thus in (10)

$$f(\chi) = \int_0^\infty - \left(\frac{\partial\phi}{\partial z}\right)_{z=0} J_0(\chi\rho)\rho d\rho, \tag{13}$$

$$= \int_0^a U J_0(\chi\rho)\rho d\rho + \int_a^\infty (0) J_0(\chi\rho)\rho d\rho, \tag{14}$$

$$= \frac{Ua}{\chi} J_1(\chi a) + 0. \tag{15}$$

Substituting the value of $f(\chi)$ from (15) in (9), we find that the velocity potential at *any* point in the semi-infinite space on one side of the baffle is

$$\phi_P = aU \int_0^\infty e^{-\lambda z} J_0(\chi\rho) J_1(\chi a) \frac{d\chi}{\lambda}. \tag{16}$$

The above method of approach is that used by L. V. King,[4] and it is reproduced here slightly elaborated for the convenience of readers and students of the subject. If the unbaffled oppositely vibrating disk is treated in the same manner, the formula for ϕ_P at any point is identical with (16), since the boundary conditions in the two cases are the same.

Using (16) as a starting point, King reproduces Rayleigh's formula (got from (5)) for the resistance and inertia components of the *total* reaction on one side of the disk. He also confirms formulæ obtained from (15) by one of us for the sound distribution in space,[5] and for the pressure at the edge and centre of the disk.[6] Furthermore, Backhaus[7] has obtained formulæ from (5), for the distribution near to the disk, and he has confirmed his results experimentally. He has also confirmed the formulæ for the sound distribution at points far away from the disk.

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[4] *Canadian Journal of Research*, **11**, 135, 1934.

[5] *Proc. Roy. Soc.*, **A122**, 604, 1929, or "Loud Speakers," p. 95.

[6] *Phil. Mag.*, **14**, 1012, 1932, or "Loud Speakers," p. 49.

[7] *Annalen d. Physik*, **5**, 1, 1930.

It follows, therefore, that Ballantine's statement concerning the misuse of (5) by the textbooks is erroneous. This is extremely fortunate, since (5) has been used more, perhaps, in modern acoustical work than any other formula.

2. It may be of interest to indicate three ways of finding the velocity potential on one side of a vibrating infinite plane.[8]

(1) The velocity potential at any point external to a radially pulsating sphere (harmonic motion) is [9]

$$\phi_P = UR^2 \frac{e^{-ika}}{r} \frac{f_0(ikr)}{F_0(ikR)}, \tag{17}$$

where R is the radius of the sphere, a is the radial distance of P therefrom, and $r = R + a$. When $R \to \infty$ and a is finite, $f_0(ikr) = 1$ and $F_0(ikr) = ikR$, so (17) degenerates to

$$\phi_P = \frac{U e^{-i(ka+\pi/2)}}{k}. \tag{18}$$

(2) Here we consider the oppositely vibrating disk, and let the radius $\to \infty$. It is immaterial whether we regard the vibrator as being circular or square. Referring to Fig. 3, the velocity potential at P due to an element of area $dy \cdot dx$ on the vibrating plane is from (5)

$$\text{v.p.} = \frac{U}{2\pi} \frac{e^{-ik\sqrt{a^2+y^2}}dx}{\sqrt{a^2+y^2}} \cdot dy, \tag{19}$$

where U is the normal velocity of one face of the plane vibrating sinusoidally. The velocity potential at P due to an infinite strip of width dx (substantially an infinite line source) is

$$d\phi_P = \frac{U}{\pi} \cdot dx \cdot \int_0^\infty \frac{e^{-ik\sqrt{a^2+y^2}}}{\sqrt{a^2+y^2}} dy,$$

$$= \frac{Udx}{2i} H_0^{(2)}(ka), \tag{20}$$

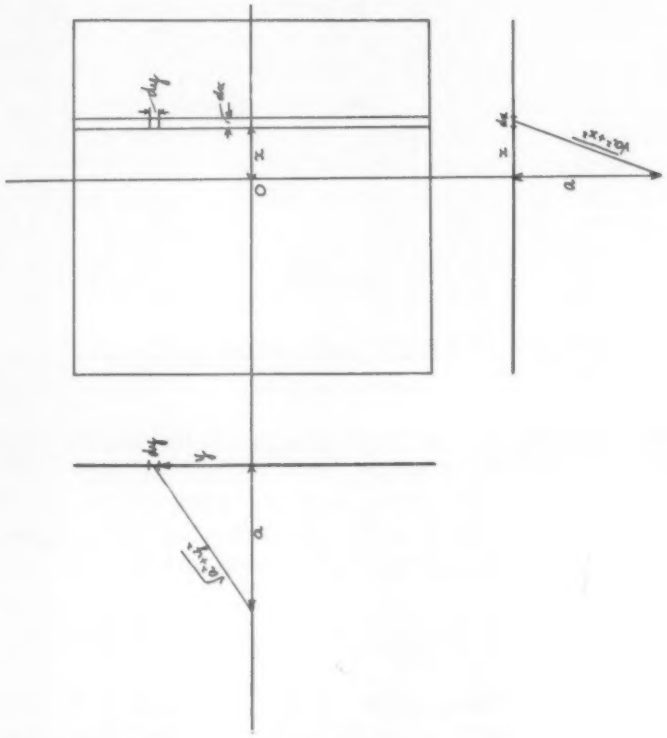
where $H_0^{(2)}(ka) = J_0(ka) - iY_0(ka)$ is Hankel's Bessel func-

[8] The infinite plane is, of course, to be regarded as the limiting case of a very large finite disk or other plane surface.

[9] Rayleigh, "Sound," Vol. 2 (1896), p. 239, or "Loud Speakers," p. 25.

tion. To obtain the velocity potential at P due to the entire plane, we must integrate with respect to x from $-\infty$ to ∞.

FIG. 3.



Thus by aid of Fig. 3 we see that

$$\phi_P = \frac{U}{i}\int_0^\infty H_0^{(2)}(k\sqrt{a^2+x^2})dx,$$

$$= \frac{U}{ik}(\cos ka - i\sin ka),$$

$$= \frac{U}{k}e^{-i(ka+\pi/2)}. \qquad (21)$$

(3) Using formula (16), we have to find the velocity potential at any finite distance from the disk when its radius tends to infinity, and it can be regarded as an infinite plane.

The main contributions to the integral occur in the region of $\chi = 0$. Thus writing a for z and R for a, we obtain

$$\phi_P = RU \int_0^\infty e^{-ika} J_1(\chi R) \frac{d\chi}{ik}$$

$$= \left[\frac{RU\, e^{-ika}}{ik} \cdot \frac{J_0(\chi R)}{R} \right]_0^\infty$$

$$= \frac{U}{k} e^{-i(ka+\pi/2)}. \tag{22}$$

DISCUSSION.

BY

STUART BALLANTINE,

Boonton, New Jersey.

My remarks on the applicability of Rayleigh's theorem to the piston-baffle problem were concerned only with the general case. In the special case of a *plane* piston and *plane* baffle, as contemplated in the discussion by McLachlan and McKay, the φ-integral which occurs in the general theorem

$$\varphi = \frac{1}{4\pi} \int\int \left[\frac{\partial \varphi}{\partial n} \frac{e^{-ikr}}{r} - \varphi \frac{\partial}{\partial n} \left(\frac{e^{-ikr}}{r} \right) \right] dS, \tag{1}$$

when taken over the surfaces of the piston and baffle, is equal to the $\partial\varphi/\partial n$-integral over the surface of the piston and the result is given by

$$\varphi = \frac{1}{2\pi} \int\int \frac{\partial \varphi}{\partial n} \frac{e^{-ikr}}{r} dS. \tag{2}$$

Such a simplification will not occur so conveniently in all piston-baffle problems. It will not occur, for example, in the case of a curved baffle nor in the case of a plane baffle and curved piston. In the latter case in order to provide the symmetry necessary for the introduction of the plane baffle without disturbing the field, we may employ an image of the piston in the plane surface. This image, as well as the vibratory surface itself, cannot be a source of the type represented

by equation (2) because of radiations from the rear but must be of the composite type illustrated in Fig. 3*c* of my paper and based upon the more general theorem (1).

In the paper under discussion I wished to emphasize the advantages of the general theorem (1) over either (2) or its companion as a starting point in acoustical investigations connected with vibrating surfaces. The indiscriminate use of (2) and its endowment with a generality which it does not possess will lead to trouble in any but the simplest cases. If, as in the case of the plane piston and plane baffle, it is found that (1) degenerates into one of the simpler forms, so much the better. In a logical development of the subject, however, this should be demonstrated in such cases.

Smoke Eliminated by Super-Sound Wave.—(*Power Plant Engineering*, Vol. XLI, No. 3.) Super-sound waves are employed in a device invented by H. W. ST. CLAIR, metallurgist, U. S. Bureau of Mines, to solve the smelter-fume problem, and should also be of value in helping to curb the smoke nuisance in large cities. It has long been known that, when sound waves are passing through a tube containing a fine powder, the powder will be concentrated at points that are free from vibratory motion. It has also been known that waves of extremely high frequency affected the diffusion of solid or liquid particles in a gas. No practical application has previously been made of this knowledge. The St. Clair method merely passes the smoke or fume through a tube in which standing sound waves are established. These standing waves are produced by so adjusting the length of the tube that waves reflected from the upper end are in phase with the original waves set up at the lower end. In order that the process may work at its best, the wave-length used must be approximately equal to the diameter of the tube. For a tube of practical diameter this means that the frequencies used will vary from 3 to 20 kilocycles per second. To generate sound waves of this frequency, several types of equipment may be used. Mr. St. Clair has used what is technically known as the magnetostrictive method, but for purposes of popular demonstration, an acoustic generator is used. This, in fact, is merely a shrill whistle. The sound waves produced by the whistle are reflected in phase with the original waves from the top of the tube and cause the solid particles to fall out of the gas stream. The action is similar to the effect produced by drawing a bow of a violin over a metal plate on which dust particles are deposited, when the vibrations cause the particles to arrange themselves in groups.

R. H. O.

TRADITIONAL IDEOLOGY.

BY

A. A. MERRILL.

Few people realize that training in the physical sciences creates as a sort of by-product, a *non*-traditional ideology. Perhaps the three men most responsible for starting the growth of this ideology were Bacon, Galileo and Descartes, all born in the latter half of the 16th century. By "ideology" I mean a group of ideas which determine the quality of one's standards of worth-while-ness. An "ideology" in metaphysics is something like a gravitational field in physics, which field determines length, inertial mass giving the "t" unit, and "straightness" giving the local geometry.

This ideology of science exists coincident with a traditional ideology. They are constantly at war with each other, sometimes in the same individual, but it is certain that the ideology of science is winning the war. The history of the last fifty years proves that. The difference between the two ideologies is that although both deal with the here-now, traditional ideology always looks backward for its standards, whereas science never looks backward for its standards. Science tests everything in the here-now and always keeps its face turned towards the future. Science is like perpetual youth; life is always *before* it.

For six thousand years at least, civilizations, differing superficially, have always had one important characteristic in common. All of them have been based upon a traditional ideology and have taught that civilization must be so based. Only since the great war have people begun to realize the great change science is causing. Without any conscious intention on their part, the work of all scientists is slowly killing traditional ideology, and substituting an experimental *non*-traditional ideology. Whether we like it or not, that is what is actually happening, as all scientists well know, if they think about it.

Greenhouse With Solid Flat Roofs Built to Resist Hailstones.—(*Engineering News Record*, Vol. 118, No. 8.) On one of the highest pieces of ground in Forest Park, St. Louis has recently been built a new floral conservatory whose design is said to mark the first radical change in greenhouse construction in many years. The novelty is evident particularly in the setback solid roof construction in contrast to the usual glass which was a fair target for every hailstorm. But the building is also unique in utilizing elliptical arches for its main framing and copper for all exterior metal, to eliminate painting. Cutting down the light by the solid roofs required careful study since it might impair the efficiency of the building. Model experiments were carried out which in the end determined not only the glass wall area and the roof widths but also selection of arch instead of vertical column supports. The conservatory is 186 ft. long by 55 ft. wide in outside dimensions and 55 ft. high. The side walls are terraced to a central roof 24½ ft. wide. The terraces are of varying widths. The total glass area is 16,654 sq. ft. The main framing consists of eight elliptical rolled-section arches and the design is said to have been made to resist a 100 mile wind. The building is equipped for scientific operation. The basement under the rear end of the building contains a heating plant consisting of an automatic oil-fired boiler, also a manually fired coal or wood boiler for emergency service. Since no reliable scientific data on the relative efficiency of radiators, pipe coils or convectors could be discovered, the city chose wall type radiators and made provisions for expansion of the system, particularly at an upper level, if it is found necessary. Ventilation is provided by manually operated movable sash.

R. H. O.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

SOME PROBLEMS CONNECTED WITH A STRATOSPHERE ASCENSION.*

BY

JEAN and JEANNETTE PICCARD.

The organization of a stratosphere flight is not essentially a problem for the free balloon pilot. It is above all a problem for the engineer and especially for the chemical engineer.

Air Conditioning. A crew of two absorbs per minute about 1500 to 2000 cc. of oxygen and replaces it by a similar volume of carbon dioxide. The carbon dioxide vapor tension of venous blood corresponds to eight per cent. carbon dioxide. If the air we breathe contains this much carbon dioxide, we cannot eliminate carbon dioxide from the body and death results. Two per cent. causes no bad effect and it was considered the upper limit to be allowed in the balloon.

Our method of air-reconditioning required 1.7 kg. of liquid air for 10 hours and consisted in replacing the 2000 cc. of spent oxygen and extracting chemically the 2000 cc. of carbon dioxide produced per minute.

Two methods are feasible for the removal of carbon dioxide. If no artificial circulation is used, a flat bag 2×2 feet in size and filled with alkali will keep the carbon dioxide content under 2 per cent. in a room in which two men are breathing.

In his flights Auguste Piccard used the Draeger apparatus. By adding oxygen to the air and blowing the mixture over granulated potassium hydroxide, this instrument provides 100 liters of fresh air per minute. It has the disadvantage that something may go wrong which will need repair and, further, the rapid flow of air over the alkali may charge the atmosphere with alkali dust. As a matter of fact, Cosyns in his last stratosphere flight suffered from coughing spells.

* An abstract of a paper published in full in *Industrial and Engineering Chemistry*, **27**, 121 (1935).

Therefore, we decided to use alkali bags. Potassium hydroxide on asbestos was the alkali chosen first. But we did not know how dry our air would be and too damp air could easily cover the grains with a solution of carbonate and greatly reduce the efficiency of the agent. Therefore, a second set of bags was filled with sodium hydroxide in flakes. The calculated amount necessary for a 10 hour flight is 4.7 kg.; we took 7 kg. During the time spent in the stratosphere both chemicals were observed to work very well.

In one previous stratosphere ascent the observers were soaked to the skin by water dripping from the upper part of the gondola. Therefore, we filled another set of bags with anhydrous magnesium perchlorate. This kept the humidity within very low limits. Small amounts of the material were also placed between the two glass plates of the windows and inside the cosmic ray apparatus.

The bottom of each bag of alkali or perchlorate contained a small amount of absorbent wood cellulose to prevent any possibility of dripping.

In addition, 9 kg. of silica gel were carried to absorb those organic chemicals (mostly of an unknown nature) which cause the difference between fresh and stale air.

Auguste Piccard found that the temperature in a white gondola is uncomfortably low so, following his suggestion, the lower part of the gondola was painted black and the upper part white. The lower half absorbs more of the sun's heat, producing a natural air circulation inside and resulting in a comfortable temperature (usually 65° F.) throughout the flight. The chemical composition of the white pigment is of the utmost importance because some white paints absorb infra-red rays and become just as hot in the sun as black paints.

For reasons of safety, the carbon dioxide determinations had to be performed without the use of strong alkali or mercury. The method adopted was developed in collaboration with Martin Hankee at the University of Chicago. A dozen stoppered tubes of 55 cc. capacity each contained 5 cc. of 0.01 N sodium hydroxide solution, colored with a trace of phenolphthalein. For the determination of carbon dioxide during the flight, one tube was opened, its air changed

by means of a small syringe, and the tube closed and shaken violently. The time of shaking necessary to destroy the red color was our measure of carbon dioxide content. During the flight in the stratosphere our analyses never showed more than 1 per cent. carbon dioxide.

The "weighing off" of the immense balloon without shaking the delicate cosmic-ray instruments presented a peculiar problem. The "load ring" was attached with four strong ropes to four mooring masts, and the ballast was adjusted in such a manner that the ropes left the load ring in a horizontal direction. Then one bag of ballast was given out and the four ropes cut loose from the gondola by means of electric blasting caps.

For ballast, 700 lbs. of fine lead shot could be released through an air lock. And sixteen 80 lb. sandbags, carried outside, could be opened from inside the gondola with blasting caps.

The rubberized valve-rope entered the gondola through a greased rubber tube. Our gondola was made of a light magnesium alloy which is very hard. Although stronger than aluminum, the additional strength is of small advantage, since the walls cannot conveniently be made thinner than 3.5 mm. Soft aluminum of this thickness is sufficiently strong and weighs only 50 per cent. more. Aluminum has the further advantage of holding lacquers better and being far less subject to corrosion. The lighter magnesium alloy is particularly advantageous for inside shelves, the floor, and the supporting struts.

THE CORPUSCULAR THEORY OF THE PRIMARY COSMIC RADIATION.*

BY

W. F. G. SWANN.

The approximately exponential law of cosmic-ray absorption is, at first sight most readily accounted for by the hypothesis that the primaries are composed of photons.

* An abstract of a paper which appeared in full in the *Physical Review*, 48, 641 (1935).

However, latitude and asymmetry effects demand that at least 31 per cent. of the primary radiation be attributed to charged particles. This is enough to spoil the exponential law given so readily by photons unless the charged particle hypothesis be developed so as to give an exponential law. The naïve hypothesis that the exponential law is to be provided by a suitable range of penetrations of the incoming rays, resulting from a corresponding range of energy distribution is found untenable, mainly because such a hypothesis would lead to a condition in which the quality of the measured radiation was independent of altitude. The paper reviews a hypothesis already published by the writer to the effect that the primary rays produced secondaries in number per centimeter of path proportional to the primary energy. These secondaries perpetuate the primary path. They represent the rays actually measured, and the theory gives an exact exponential law. The theory gives, in fact, a constant "apparent" coefficient of absorption of the measured effect which is independent of the primary energy. This result requires modification to harmonize with the data on the latitude and directional effects. It is shown that harmonization is provided by a modification of the theory which permits an increase of coefficient of apparent absorption with decrease of primary energy. It is found that such a modification can be readily made in more ways than one. It is then shown that the apparently contradictory phenomenon involved in the "hardening" of the average radiation with passage through matter can readily be accounted for by adding to this hypothesis already made, the known fact of a distribution of energies in the incoming primary corpuscular radiation. A modification of the foregoing theory permits the "apparent" primaries referred to in it to be really photons produced by impact of true primary charged particles with the upper atmosphere. The writer reviews a former hypothesis made by him with regard to the dependence of shower production and atomic burst production in lead, a hypothesis designed to provide an explanation that these phenomena increase with altitude much more rapidly than does the measured cosmic-ray intensity. It results that the extension of the main theory concerned with absorption of the primary

energy when combined with the hypothesis concerning burst and shower production results in harmonization of all the details of these phenomena as far as they are known. A list of eleven facts concerned with cosmic-ray absorption, latitude and directional effects, burst and shower production is made. The list comprises all of the outstanding facts concerned with the subject; and it is shown that the extended theory harmonizes all of them.

THE EFFECT OF PRIMARY COSMIC-RAY ENERGY UPON BURST PRODUCTION.*

BY

W. F. G. SWANN and D. B. COWIE.

The fact that the intensity of burst and shower production increases with altitude much more rapidly than does the cosmic-radiation intensity itself led one of us to the view that the intensity of burst production was a rapidly increasing function of the energy of the primary cosmic rays. If such is the case, burst production per unit intensity of primary, by primary rays which are limited to a vertical direction, should be much larger than the corresponding quantity for primary rays limited to directions in the neighborhood of 45 degrees, since the latter rays have traveled a much greater thickness of atmosphere. To test this conclusion we set up an apparatus comprising a one-inch thick iron sphere suitably arranged as a burst-measuring ionization chamber. One set of counters was placed vertically above and another was placed vertically below the center. The two were used as a double coincidence set. Coincidences between the counter discharges and the bursts produced serve to indicate which bursts were produced by the vertical rays determined by the counter system. An exactly similar pair of counters arranged at 45 degrees to the vertical gave the information for this direction also. The experiments show that while over a period of 300 hours the numbers of

* An abstract of a paper which appeared in full in the *Physical Review*, **48**, 649 (1935).

counts obtained by the vertical and 45 degree counters were in the ratio of 1.5 to 1, the corresponding numbers of bursts (involving more than 2×10^6 ions) were in the ratio of 10 to 1, which result confirms the conclusion cited above. It is possible to calculate from the experiments of C. G. and D. D. Montgomery at sea level and at Pike's Peak the magnitude of the effect to be expected in the present experiment on the basis of the general ideas formulated as controlling the phenomenon. The agreement obtained is within the limits of accuracy of the experiments.

ON THE SHOWERS OF RAYS WHICH PRODUCE BURSTS OF COSMIC RAY IONIZATION.*

BY

C. G. MONTGOMERY and D. D. MONTGOMERY.

In general, two methods have been employed in the investigation of showers of ionizing rays produced by cosmic radiation. One of these methods involves the use of an ionization chamber; the other, the simultaneous discharges of several Geiger-Müller counters placed out of line. Observations made by means of an ionization chamber are limited to those rather large sizes of showers which are not obscured by the statistical fluctuations in the cosmic ray ionization. The interpretation of data obtained with Geiger-Müller counters, on the other hand, is rendered ambiguous by the fact that many showers are missed, and that the number of showers counted depends not only upon the geometrical configuration of the counters but also upon the density of rays in a shower. It has been customary to imply that the showers measured by these two methods differ inherently from each other. Indeed the showers observed in ionization vessels have been referred to specifically as Hoffmann Stösse, or atomic bursts. Evidence is given here to support the view that there is no marked discontinuity between large and small showers but that all are represented in a continuous gradation in size.

* An abstract of a paper published in full in the *Physical Review*, 48, 786 (1935).

If we assume that the rays of a shower are randomly distributed, then the probability that a group of counters will be discharged by a shower is

$$\sum_{j=0}^{r} \frac{r!(-1)^j}{j!(r-j)!}(1-jp)^N, \qquad (1)$$

where r is the number of counters, N the number of rays in the shower, and p the *a priori* probability that a ray of the shower will strike a counter. It is possible to test this frequency formula experimentally by utilizing the fact that the sizes of bursts measured in an ionization chamber are proportional to the numbers of rays in the corresponding showers. The fraction of the total number of bursts of ionization of any given size which occur simultaneously with the discharges of a group of counters suitably arranged is calculable through (1) and can also be measured experimentally, so that the principles underlying (1) can be tested. The apparatus used consisted of a spherical ionization chamber of magnesium above which was placed lead, as a source of showers. Under the sphere were placed three groups of three Geiger-Müller counters, the counters in each group being connected in parallel. The three groups were placed out of line with the center group below the other two, so that a ray passing through the sphere could pass through only one group of counters. The fraction of the number of bursts of ionization which were accompanied by a discharge of the counters was determined for showers having more than 60 rays. The ratio of the mean solid angles subtended by the sphere and by one group of counters at the lead is the value of the *a priori* probability, p, associated with that group, and was equal to 0.01.

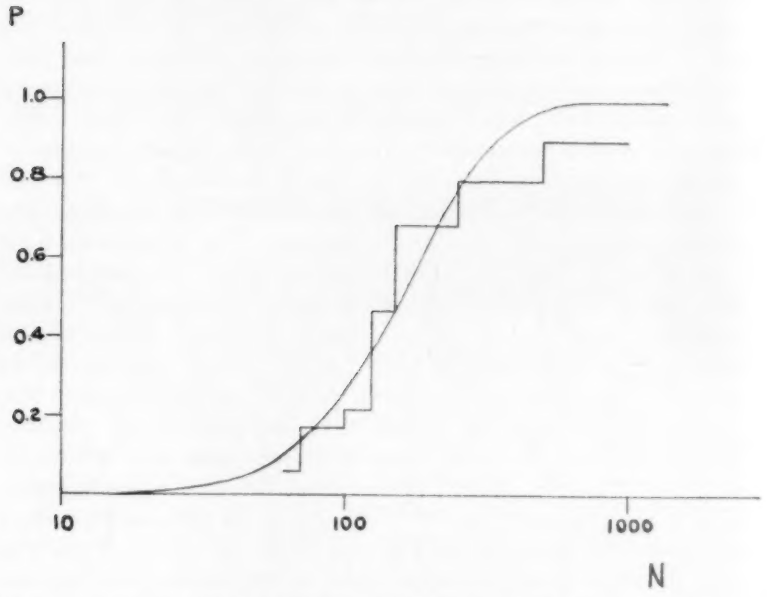
In Fig. 1, the smooth curve represents the theoretical probability, the block one the experimental data. It is to be noted that there are no arbitrary constants to be adjusted. Similar experiments have been performed, with other ionization chambers and other arrangements and numbers of counters, which, although the data are more fragmentary, agree with expectation as well as the experiment here described.

In the foregoing section we have given an answer to the

question, "How many bursts of ionization of a given size are accompanied by a discharge of the three counter groups?" Let us now invert the question and ask, "What fraction of the total number of the simultaneous discharges of the counters is produced by showers of a given size?"

If showers containing N rays occur at the rate $R(N)$, and if the probability of a shower being recorded is $P(N)$, then

FIG. 1.



Observed and calculated fractions of the number of bursts of ionization occurring simultaneously with a discharge of the counters.

the counting rate, C, will be given by

$$\sum_{N=1}^{\infty} R(N)P(N).$$

Since we know $R(N)$ from the ionization data, it should be possible to compute the total counting rate of the counters used in the experiment described above, and compare it with the observed rate. It is necessary to know the distribution function, R, for values of N smaller than it is possible to observe in this chamber, and these values must be obtained

by extrapolation. It has been found possible to represent the frequency of occurrence not only of the large showers in ionization vessels, but also of small showers observed in cloud chambers, by a relation of the form $R = A/N^s$. The function PR increases from zero, for two ray showers, to a maximum for showers of eight or nine rays, and then falls monotonically as N increases. The total counting rate thus computed is 2.5 per hour. The observed counting rate was 5.5 per hour. In view of the large range of extrapolation, this agreement is quite satisfactory, since no account has been taken of the showers which set off the counters without passing through the chamber. Further, we find that the contribution of showers below ten rays is of the same order of magnitude as the contribution of showers greater than 100 rays, and that more than half of the counts are caused by showers greater than 30 rays. This situation is not a consequence of the particular arrangement of counters considered here, but holds for most cases where counters have been used to investigate showers. Thus the phenomena which counters record are, in general, quite complicated ones.

The importance of the foregoing considerations is attested by the fact that, in investigating showers, it has been customary to use two or three counters, and regard their simultaneous discharges as evidence of the occurrence of doubles, triples, etc., at the same time regarding any discharges produced by large showers or Stösse as of such rare occurrence as to be negligible, or at any rate to figure only as a correction. We must now realize that the rarity of occurrence of the large showers is largely compensated by the large chance which they have of operating the counters, in comparison with the much smaller chance of operation that three ray showers have, for example. The net result is that the number of discharges produced by the large showers is comparable with the number produced by those which it is the object of the experiment to measure.

The authors wish to express their appreciation to Prof. W. F. G. Swann for his interest, advice, and criticism during the progress of this work, which grew out of joint investigations with him. The authors also wish to acknowledge the financial support of the American Philosophical Society in carrying out this investigation.

GEIGER-COUNTER CHARACTERISTICS WITH APPLIED POTENTIALS REVERSED.*

BY

D. B. COWIE.

The Geiger-Müller counter connected normally with the wire at a positive potential with respect to the cylinder, has been used as a means of detecting various ionizing rays. It is well known that the counting action takes place with the potentials reversed, but it has been noticed that the rate of a reversed counter is much lower than with the potentials connected in the normal direction. For example, a double-coincidence [1] circuit, in which the record was made when the two counters discharged simultaneously, recorded two rays per minute with the potentials in the normal direction, while very few were recorded in a period of twelve hours with the potentials reversed. At first sight there is nothing remarkable in this result since one may contend that the counters operate by the release of an electron from the gas by an ionizing ray, with the subsequent transportation of the electron to the central wire, where under the large fields existing there it precipitates ionization by collision. With the potentials reversed, the released electron is carried away from the wire and the conditions for ionization do not develop. However, such a view discards the possibility that a positive ion when carried to the wire under a high potential difference may precipitate a discharge by secondary actions involving the emission of electrons from the wire. Such possibilities have in fact been studied by W. E. Danforth and others.

POSSIBLE INTERPRETATION OF THE RESULTS.

Two main possibilities suggest themselves as an interpretation of the foregoing facts. The first instance, the failure of the counters to operate when used as a double-coincidence set, is to be sought in some cause which results in a time delay between the instant of breakdown of the two counters, this time delay being greater than the recovery time of the circuit

* Reprinted from the *Physical Review*, **48**, 883 (1935).

[1] The particular circuit used was that designed by G. L. Locher. The counters were argon filled, with their cylinders coated with copper oxide.

used for recording. Under such conditions the recording circuit would fail to record rays even though they had passed through both counter tubes. Single counter discharges would, however, be recorded by a circuit designed to record singles. The time delay would presumably arise from the fact that the relatively low mobility of the positive ions would insure that the liberation of such ions from the gas by the cosmic ray at different distances from the wire, would result in an appreciable difference between the instant of arrival at the corresponding wires.

A possible alternative interpretation would be that the counters are inefficient with the potentials reversed and do not respond to all radiation passing through them.

In order to test this matter, two counters were arranged with independent counting circuits, so that the recovery time of the circuits was not involved, and coincidences were judged by the simultaneity of photographs of individual counts taken upon the same recording film. Two runs were made. In each the counters were 3.8 centimeters apart, from center to center. In the first run, the applied potential of the counter reversed was just below the "plateau" of the potential-*vs.*-counting-rate curve of the normal counter. In the second run, it was well along the "plateau." The first experiment from a single counter gave 255 counts in an eight-hour run with the potentials reversed. The corresponding number of counts with the potentials in the normal direction was 2880. The value of the relative efficiency ϵ, of the reversed counter with respect to the normal counter is $255/2880 = 0.088$. Hence ϵ^2, the relative efficiency for double coincidences is 7.7×10^{-3}. The number of coincidences observed during the eight-hour run was 10, with the potentials reversed. The number of coincidences with the potentials applied in the normal direction was 960. This ratio, 10^{-4} to unity, agrees with the value 7.7×10^{-3} for ϵ^2 well within the statistical limits of accuracy determined by the 10 counts cited above.

In the second run the counting rates were different, as they should be, but the story of their ratios is as follows: With the potentials reversed, a run of 200 minutes gave 365 counts from a single counter. The corresponding number of counts for the same period with the potentials normal was

1600. The value of ϵ for this case was therefore 365/1600 = 0.23. The value of ϵ^2 is therefore 0.053. The number of reversed coincidences for this period was 21, while the normal number with potentials applied normally was 400. The ratio is 0.052, which again agrees with the value of ϵ^2.

In the foregoing experiments, the simple counter records gamma-rays as well as cosmic-ray particles, and to no negligible extent, while the coincidences between counters are concerned only with cosmic-ray particles. It is important to observe, however, that the foregoing conclusions are not vitiated by participation of the gamma-rays. For while the two sets of data from the single counter are influenced by gamma-rays as well as by cosmic-ray particles, they give the true value of ϵ, while the two experiments concerned with coincidences, though influenced only by cosmic-ray particles, give the true value of ϵ^2. All that is assumed is that the counter possesses 100 per cent. efficiency for potential applied normally, and an electron such as would be emitted by a gamma-ray from the counter wall has the same characteristics for its subsequent activities as has that charged particle which is the representative of the cosmic ray.

It is interesting to speculate as to the cause of the relative inefficiency of the reversed counter. Two possibilities suggest themselves. The first invoking only the electrons as the liberated entities responsible for the counter discharge. Since the electrons move away from the wire under the influence of the field, only those which are liberated very near the wire where the electric field is high can cause a discharge. In the case of a single counter the effect is therefore to limit the effective areas of the counter to a small region around the central wire, and so reduce the number of counts recorded. The double-coincidence counts, depending as they do upon the square of the area, will be much more affected by reversal than will the single counter; but even the single counter will be affected in proportion to the reduction of the effective area on reversal. As a matter of fact, the factor by which the single counting rate is reduced by reversal should be equal to the ratio of the effective counting area to the total counter area. We have called this factor ϵ and should expect that the coincidence counting rate would be reduced in the ratio of ϵ^2 to unity.

Considering the experimental values of ϵ, the limiting fields where an electron would just be able to produce a discharge would occur at the distance of 0.044 centimeter from the central wire for the lower voltage and in the case of the higher voltage at 0.12 centimeter from the central wire. The respective fields at these points are 4905 and 2398 volts per centimeter. Since it would be expected on this hypothesis that the fields at the edge of the sensitive volume should be identical, the discrepancy of the above values militates against the adoption of this hypothesis. The discrepancy is particularly striking if one compares these fields with the fields required for counter operation in the normal manner. At the threshold voltage the field at the surface of the wire is 54,000 volts per centimeter.

Following suggestions by T. H. Johnson and W. E. Danforth, a more probable interpretation of the inefficiency of the reversed counter can be made by supposing the counter action to be produced when a positive ion strikes the wire and liberates from it a secondary electron. Whenever an electron is so liberated a discharge results, but the probability of liberation is low. Penning [2] and others have investigated the probability of emission of secondary electrons from tungsten by impact of positive ions of several gases. The number of electrons per ion varies from 0.03 to 0.05 for energies of incident ions below 50 volts and increases nearly linearly with energy up to 0.42 for 1000-volt ions.

With the variations of the phenomenon attributable to adsorb gaseous layers, it seems probable that this range of probabilities stands in agreement with the efficiency found in the above counter experiments.

The writer wishes to express his appreciation of the help given by Professor W. F. G. Swann in formulating the final method of attack adopted in the problem.

[2] Penning, *K. Akad. Wet. Amst. Proc.*, **33**, 841 (1930).

Sound.—The American Standards Association has recently announced a standard Acoustical Terminology for sound. This standard, four years in development, is the work of engineers, musicians, manufacturers, and scientists. It will eliminate confusion in the motion picture, radio, and building fields. A broad meaning is given to the word " noise," now defined in terms of the listener as an " unwanted " sound, rather than in terms of the sound itself. A section of the standard deals with architectural acoustics, and another, which provides standard terms for the measurement of hearing, will be used widely by the medical profession and by manufacturers of aids for the partially deaf. Other parts dealing with the conversion of sound to electrical energy, and with acoustic transmission systems, will be of particular value to the motion picture and radio professions. A separate section for music brings engineers and acoustical experts into agreement with musicians on a basic standard pitch, the importance of which can be judged by the fact that an increase of only 4.14 per cent. in pitch carried out through the entire keyboard of a piano would throw an additional strain of something like half a ton on the framework of the instrument. The association has already approved two other standards in the sound field. One of these, completed eight months previous, establishes " reference " and " intensity " levels for sound measurement. The other specifies the characteristics of " noise meters " used by builders, radio engineers, and music teachers. Before this second standard became available no two meters on the market could be depended upon to register similar or even comparable results for the same sound.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

RADIO METEOROGRAPH SYSTEM.

A radiometeorograph system has been developed in the Bureau's radio section for use in the meteorological service of the U. S. Navy Department. It is expected that this system will eventually replace airplanes in gathering information on upper-air conditions required for weather forecasting.

The complete radio meteorograph system comprises transmitting equipment for sending down from small unmanned balloons meteorological observations on upper-air pressure, temperature, and humidity; receiving and recording equipment on the ground for automatically plotting these data in the graphical form desired by meteorologists; and direction finders (also at the ground station) for tracking the flight of the balloon so as to determine upper-air wind conditions.

The instrument, sent aloft on a 5-foot balloon, consists of a miniature radio transmitting set, batteries, and a meteorograph. The latter contains the devices for measuring pressure, temperature, humidity, and other elements desired. The complete equipment is housed in a balsa-wood box $6 \times 6 \times 4\frac{1}{2}$ inches, and weighs less than 2 pounds.

The meteorograph utilizes the decrease in atmospheric pressure as the balloon rises, for moving a small switch-arm over a set of electrical contacts separated by insulating strips. The contacts are so spaced that for a decrease in air pressure equivalent to a few hundred feet rise of the balloon, the arm will move from one contact to the next. The arm on reaching selected contacts causes the radio transmitter to send down signals having predetermined audio notes which provide index marks for the pressure scale.

The contacts intermediate to the pressure-index contacts are wired to a resistor which is controlled by a bundle of human hair and hence varies as the hairs contract or expand

* Communicated by the Director.

with varying humidity conditions. The switch-arm, in passing over these contacts, switches the transmitter circuit so as to send down signals having an audio note which is proportional to the value of the resistor and hence to the humidity encountered. When the switch-arm passes over the insulating strips lying between the contacts, the frequency of the audio note is determined by the electrical resistance of a small glass tube filled with sulfuric acid. The resistance of this small column of acid changes markedly with the temperature so that the note which is sent down to the ground may be interpreted to evaluate the air temperatures at the various balloon heights. In one form of the balloon instrument, light intensity may also be measured, giving data valuable in determining the heights and vertical structure of cloud formations.

Automatic receiving and recording equipment are employed to plot these data graphically on a chart which moves under a pen controlled by the received signals. The pen sets itself according to the pitch of the audio note. The final record gives a complete picture of the variation of temperature, humidity, and any other elements included, as a function of height above the earth's surface.

Aside from the fact that this system provides meteorological observations to much greater heights than can be obtained by airplane ascents, and under all conditions of weather, the radio meteorograph affords still another important advantage over airplanes in that it permits the use of radio direction finder methods for tracking the path of the balloon, thereby giving data on upper-air wind conditions. To evaluate upper-air wind velocities, it is necessary to measure continuously the distance and azimuthal direction of the balloon from the ground station. Usual direction-finding methods, if applied to this problem, would require two or more ground direction finding stations separated by from 10 to 20 miles. The radio meteorograph system contemplates the use of a single ground station, at which both the azimuthal direction and the angle of elevation of the balloon are measured. Initial experiments have been made on a specialized method for measuring the angle of elevation. This has hitherto not been considered feasible because of the electrical properties of

the ground. Knowing the angle of elevation and the height of the balloon (the latter from the graphical indications of pressure, temperature and humidity), the distance of the balloon from the ground station may be computed.

The radio meteorograph has several important advantages over other arrangements, because the air pressure does the switching. No rotating parts of external motive power are required. The instrument thus becomes simple to construct and low in cost. The latter is essential if the radio meteorograph is to replace the use of airplanes in this service.

The number of observations obtained during an ascent is independent of the rate of ascent of the balloon. If desired, a high rate of balloon ascent may be used in order to reduce the total time required for receiving a complete set of observations. To take full advantage of this feature, it is necessary that the temperature and humidity devices respond with sufficient speed to changes in these elements. The temperature device employed meets this requirement. Preliminary experiments are now being made which it is hoped will lead to the development of a humidity device suitable to this purpose.

PERFORMANCE CHARACTERISTICS OF A WATER CURRENT METER.

In determining rates of flow in streams, rivers, and watersheds, to obtain information necessary for flood control and the development of water resources, the question has arisen as to the effect of the density of the fluid on the indications of the current meter by which the velocity of the flowing water is measured. The current meter used is generally of either the propeller or cup wheel type which indicates the water velocity by the rate of rotation of the propeller or cup wheel. These instruments are calibrated by towing through still clear, water in a rating tank. In the field the meters are sometimes used to measure the velocity of salt water, and if density affects the rate of the instrument the indicated velocities will be in error because the density of the salt water is higher than that of the fresh water in the rating tank. Again flood waters may contain large quantities of silt and mud, producing a mixture which is more dense than clear

water. Whether the effect on the meter is the same as that which would be produced by a homogeneous fluid of the same density is difficult to answer. Certainly, one effect of silt and mud is to increase the inertia of the fluid and to this extent the effect on the indications of the meter will be similar to that of a fluid of greater density.

The effect of density on two water current meters of the cup wheel type, known as the small Price meter, was studied by G. B. Schubauer and M. A. Mason at the Bureau by calibrating each meter, first in water by the usual towing method, and second in air by placing them in the wind tunnel. By the change from water to air a change in density by a factor of approximately 800 was secured. Two meters of the same type were tested in this way to avoid possible errors due to irregularities in any one meter.

Dimensional considerations showed that the number of revolutions of the cup wheel during 1 foot of travel of the fluid should be a function of the product of velocity by the square root of the density of the fluid, provided the bearing friction is constant and the Reynolds Number is without effect on the performance of the instrument. Tests showed the effect of the Reynolds Number to be negligible and verified the foregoing functional relationship. The form in which the variables occurred indicated that changes in bearing friction were just as important as changes in density, a given percentage increase in friction having the same effect as the same percentage decrease in density.

It was concluded that the changes in density ordinarily encountered in the field would have an entirely negligible effect on the accuracy of the meter. In so far as an effect from this source is concerned the mud in the stream may be ignored. However, if particles of mud or silt get into the bearings, it is conceivable that changes in bearing friction can occur large enough to cause important errors.

RP981 in the March number of the *Journal of Research* should be consulted for a complete account of this work.

CALIBRATION OF A "CONSTANT RATE OF LOADING" MACHINE FOR TESTING TEXTILES.

In an article prepared for Rayon Textile Monthly two methods are described for calibrating a "constant rate of loading" machine of the tilting plane and rolling cart type which has recently come into use in the textile industry. The use of this type of machine is provided for in the "Proposed Tentative Specification for Textile Testing Machines," A. S. T. M. designation D76–35T, but no method is given for its calibration either in the specification or in the literature describing it.

One method is based on the use of a pulley and weights and the other on the use of calibrated springs. A typical load-elongation curve for both loading and unloading is shown and the significance of its various parts is discussed in relation to use of the calibration.

REACTION OF WOOL WITH STRONG SOLUTIONS OF SULFURIC ACID.

The use of strong solutions of sulfuric acid for the removal of cotton from mixtures with wool has been recommended by a number of investigators. In addition, sulfuric acid is widely used in wool manufacturing in the dyeing and the carbonizing processes.

It has been shown that wool reacts with strong sulfuric acid to form a relatively stable compound. The combined acid cannot be removed by prolonged washing with water or alkaline reagents. An investigation was, therefore, undertaken at the Bureau to determine the nature of the reaction and to study some of the properties of its product. It is reported in the *Journal of Research* for March (RP980, by Milton Harris, Ralph Mease and Henry Rutherford).

Data have been secured on the way in which wool is affected by treatment with solutions of sulfuric acid of different concentrations at 5, 25, and 50° C. for 15 minutes, and with an 80-per cent. solution of sulfuric acid at 25° C. for different lengths of time. The results suggest that strong sulfuric acid reacts with the basic groups in wool to form sulfamic acid derivatives. The acid-combining capacity de-

creases and the base-combining capacity increases in proportion to the number of sulfamic acid groups formed in the wool.

FIELD TESTS OF NON-BITUMINOUS PIPE COATINGS FOR UNDERGROUND USE.

The study of metallic pipe coatings was begun at the Bureau in 1922 and the study has been extended from time to time. The latest results of this study are given in a paper (RP982) by K. H. Logan and S. P. Ewing in the *Journal of Research* for March.

Two varieties of aluminum-coated pipe (calorized pipe) were exposed to three soils for 10 years. The coatings materially reduced the rates of corrosion in most of these soils, but complete protection was secured in none of them.

Although lead is resistant to corrosion in most soils, especially those containing sulfates, many soils are sufficiently corrosive to penetrate a thin lead coating within a few years. When the iron or steel beneath the coating has been exposed, galvanic action between the two metals frequently accelerates the corrosion of the ferrous metal, and the lead-coated pipe may be punctured before an uncoated one of the same pipe-wall thickness. For these reasons lead coatings similar to those tested, of average thickness up to 1.5 mils, do not afford adequate protection against soil corrosion.

Hot dipped zinc coatings (galvanized coatings) have been studied to discover their resistance to different types of soils and to determine the effects of the thickness of the coating and of the character of the base metal to which the coating is applied. In most soils serious pitting does not occur until nearly all of the zinc has been removed from the specimen. The rate of loss of weight of galvanized steel is less than the rate of loss of either zinc or steel. The reason for this is probably the peculiar variation of potential of galvanized coatings as the metal is removed, which property tends to oppose any galvanic currents, set up by soil corrosion. There was no noticeable difference in the rates of corrosion of galvanized coatings in different base metals. Thicker galvanized coatings are better than thin ones; the minimum

thickness for adequate protection in most soils is approximately 2 oz. per square foot of surface.

The results of testing a group of non-metallic, non-bituminous coatings are given. As in earlier experiments, thin coatings involving the use of a volatile solvent proved unsatisfactory. A vitreous enamel and two rather thick hard-rubber compounds withstood the action of corrosive soils very satisfactorily for two years. The test of these materials is being continued.

SURFACE TENSION OF MOLTEN ENAMELS.

The surface tension of molten enamels, within the temperature range in which they are fired on metal shapes, has long been a matter of interest to the industry because certain troublesome surface characteristics, including those known as "orange peel" and "crawling," have been supposed to be caused wholly or partly by improper surface tension. As a part of a long-range plan of study, the surface tensions of eight commercial type enamels, representative of as many classes, are being determined. The method being used is to weigh, by means of a torsion wire balance with optical lever, the amount of enamel which is supported through surface tension acting on a hollow platinum cylinder. This cylinder is suspended with its bottom edge at the normal surface level of the enamel.

Due to the high apparent viscosity of enamels in this range of temperature (approximately 500 to 25,000 poises) the time required to reach equilibrium would be many hours were the system not forced to a condition near equilibrium. When this precaution was taken, however, and equilibrium approached from both sides, it was possible in tests made so far to obtain satisfactory results. A "soft" ground coat and cover coat, and a "hard" ground coat, all gave results approximating 240 to 250 dynes per cm. surface tension. Additional tests are in progress.

ANALYSIS AND SPECIFICATION OF COLOR.

Methods of analyzing and specifying colors are discussed by Kasson S. Gibson in a paper which will be published in the *Journal of the Society of Motion Picture Engineers*.

Doctor Gibson points out that color is an important factor in nearly every article of commerce, affecting its sales value in one of the following three ways:

(1) The color may be the primary property because of which the article is desired. This is true of dyes, pigments, and paints.

(2) The color may be an indication of the quality or identity of an article, as in the case of vegetable and mineral oils, sugars and syrups, dairy products, flour, glass, paper, and raw materials, such as cotton, wool and silk.

(3) The article may be artificially colored for the purpose of producing and increasing sales appeal. Such materials include textiles and wearing apparel of all kinds, automobile finishes, furniture, enamels and porcelains, and candy and other food stuffs.

The annual trade value of these materials is in the billions of dollars. The analysis and control of colors is thus seen to be a matter of great importance in commerce and industry. When one realizes that there are millions of perceptibly differing colors, any of which it may be desired to analyse and specify, the necessity of colorimetric research and testing can readily be understood.

Various methods of describing colors and of measuring and specifying color stimuli are available, the character of the problem determining which of these is most suitable. The methods discussed include: (1) color names, (2) systems of material color standards, (3) colorimeters, (4) colorimetric computations based on spectrophotometric data. The colorimetry of both illuminated objects and illuminants is considered, together with various methods of colorimetric specification.

NEW CIRCULAR ON INKS.

A new circular on inks (C413) was received from the printer last month. It is the fourth publication on this sub-

ject which the Bureau has issued, the last one being Circular C400 which was published in 1933.

The new circular, which supersedes all those previously issued on this subject, stresses more particularly methods for making ink, although testing procedures are included. As in the previous circular, the appendix contains a list of suitable dyes, and conversion factors which will be found useful when formulas are given in the metric units. A brief historical summary and descriptions of the various kinds of inks, grouped in two major classes, with sections on such subjects as aging of writing, restoration of faded writing, and ink eradicators, make the circular a reasonably complete and extremely interesting treatise on this popular subject.

Copies of C413 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

Record Breaking January Drought, Floods, Freezes and Early Blooms.—The year 1937 began with a month that will go down in weather history as a breaker of records for moisture, heat, and cold, a month of extreme contrasts, according to J. B. KINCER of the Weather Bureau. The outstanding result of the abnormal January weather is the devastating flood carried down to the Mississippi by the Ohio River and its tributaries. From January 1 to January 25 the clouds poured down on thousands of square miles of land a layer of water that would have been nearly 16 inches deep if none had run off. For example, a belt 100 miles wide, extending roughly 50 miles on each side of the Ohio River, and about 550 miles long—from the West Virginia boundary line to the Mississippi—was deluged with more than 60 billion tons of water. "This is too vast to register in the human mind," Mr. Kincer says, "so we may put it in another way. To count these 60 billion tons of water, at the rate of 3 a second, keeping at it continuously day and night would take more than 500 years." Practically all of this rushed down into the streams. Already saturated with the December rainfall, the ground was incapable of absorbing any part of the January rains. Despite these unwanted rains in the East and helpful snows over most of the West, the need for more precipitation was acute in the Great Plains where the soil remained dry and subject to dust storms. The unseasonable freezes in southern California called for the use of millions of orchard heaters to save the citrus fruit crop. In marked contrast to these low temperatures were the high ones in the Southeast, where the extraordinary heat advanced vegetation precariously far beyond its normal stage.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, MARCH 17, 1937.

The regular monthly meeting of the Institute was held this evening at 8:30 o'clock.

In the absence of the President and the Vice-presidents the meeting was called to order by the Secretary.

The minutes of the previous meeting were approved as published in the March issue of the JOURNAL.

The additions to membership since last meeting are as follows: Institute, 20; Museum, 63; total for the month, 83; total of all classes of membership at this date, 6,038.

Announcement was made of the death of Prof. Lewis M. Haupt on March 10th and that of Dr. Elihu Thomson on March 13th. Both gentlemen had been active in the many affairs of the Institute for sixty-three years.

An amendment to the By-Laws providing for the increase of the membership of the Committee on Science and the Arts from sixty to sixty-six, having been presented in proper order and having the approval of the Board of Managers, was unanimously adopted.

The Chairman announced that the Planetarium would hereafter be open on every day in the week, including Monday and Tuesday. Demonstrations would be given at three and eight-thirty o'clock with special showings on Saturdays, Sundays and holidays.

Mr. J. Howard Pew, President of the Sun Oil Company, was then introduced and read an interesting paper on Industrial Growth and the Competitive System.

He outlined the economic and industrial philosophy of a business man who had spent his life in the oil industry. He gave an interesting account of his experiences during the generation that has seen the great development of the oil and automotive industries. The speaker expressed the opinion that economic and industrial development such as has characterized recent generations is possible only in an atmosphere of unrestricted competition, of encouragement to enterprise and invention, and of free and equal opportunity to everybody.

He pointed to the oil and automotive industries as young giants of the modern industrial order and argued that their accomplishment could have been effected under no other kind of economic organization. He pointed out the cause for the growth of the automobile industry and outlined the development and cause of growth of the oil industry, and indicated how revolution in industry is brought about by the pressure of persistent competition.

The thanks of the meeting were conveyed to the speaker by the Chairman.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

RESOLUTION PASSED BY THE BOARD OF MANAGERS ON THE OCCASION OF THE DEATH OF DR. ELIHU THOMSON.

The Board of Managers of The Franklin Institute of the State of Pennsylvania records hereby its deep sense of loss in the death of Professor Elihu Thomson on March thirteenth, Nineteen Hundred and Thirty-seven.

Born in England, a life span of nearly eighty-four years was spent mostly in the United States where many active and helpful years were devoted to distinguished services in the field of science.

When Professor Thomson became of legal age he joined The Franklin Institute and continued his membership throughout his entire life. He conducted courses in the Institute, he served as a member of the Board of Managers, he was a frequent contributor to the JOURNAL, and he was a worthy recipient of the honors of The Franklin Institute.

Professor Thomson's fine qualities and kindly disposition endeared him to all who had the privilege of knowing him. His deep understanding of human nature enhanced greatly his scientific achievements.

Therefore be it

Resolved: That this expression of sorrow at the passing of a greatly esteemed member of the Institute be spread upon its minutes and that a copy be sent to Professor Thomson's family in testimony of the sympathy of the Board in its bereavement and, further, that a copy be printed in the JOURNAL OF THE INSTITUTE.

March 17, 1937.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, March 10, 1937.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MARCH 10, 1937.

DR. WINTHROP R. WRIGHT *in the Chair.*

The following reports were presented for final action:

No. 3004: Vulcan-Sinclair Hydraulic Coupling.

This report recommended the award of an Edward Longstreth Medal to Mr. Harold Sinclair, of Surbiton, England, "In consideration of the adaptation of the constant speed Föttinger type hydraulic coupling to the variable speed requirements of industrial applications."

No. 3005: Origination of the Cellophane Industry.

This report recommended the award of an Elliott Cresson Medal to Jacques Edwin Brandenberger, of Neuilly-sur-Seine, France, "In consideration of his invention and development of the process of manufacture of continuous transparent sheets of regenerated cellulose which have found a widespread use in industry."

No. 3015: Work of Dr. J. C. Hostetter.

This report recommended the award of a Howard N. Potts Medal to Dr. John Clyde Hostetter, of Hartford, Connecticut, "In consideration of the combination of technical understanding and executive ability which has enabled him

to direct the application of glass to such diversified new uses as a 200-inch telescope disc and saucepans that can be used above an open flame."

No. 3020: Work of Dr. William Bowie.

This report recommended the award of an Elliott Cresson Medal to Dr. William Bowie, of Washington, D. C., "In consideration of his contributions to the science of geodesy, particularly with reference to the theory of isostasy, the applications of which he has extended to problems in general geophysics and geology."

No. 3031: Literature.

This report recommended the award of the Louis E. Levy Medal to Dr. Inge Lyse, of Lehigh University, Bethlehem, Pennsylvania, for his series of papers on "A Study of the Quality, the Design and the Economy of Concrete," published in the April, May, June, and July issues of the Journal of the Institute for 1936.

No. 3032: Henderson Medal.

This report recommended the award of the George R. Henderson Medal to Dr. Rupen Eksergian, of Philadelphia, Pennsylvania, "In consideration of his contributions to Railway Engineering and his accomplishments in the field of railway locomotive and car design."

JOHN FRAZER,
Secretary to the Committee.

LIBRARY NOTES.

The library is open for consultation as follows: Mondays, Tuesdays, Fridays and Saturdays, 9 A.M. until 5 P.M., Wednesdays and Thursdays, 2 until 10 o'clock P.M. 704 readers consulted the library during the twenty-three days of February.

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MILLER, WILLIAM J. An Introduction to Physical Geology with Special Reference to North America. Third Edition. 1935.

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BOOK REVIEWS

ELEMENTS OF NUCLEAR PHYSICS, by Franco Rasetti. 327 pages, diagrams, 15 × 23.5 cms. New York, Prentice-Hall, Inc., 1936. Price $4.50.

In the Preface of this book there is stated, "The present work originated as an English edition of a volume (F. Rasetti, Il Nucleo Atomico, Zanichelli, Bologna, 1936) written for the Italian Consiglio Nazionale delle Ricerche as a part of a general treatise on physics. However, to incorporate recent findings that have resulted from the exceedingly rapid development of nuclear physics during the period of about one year and a half since the Italian text was written, essential modifications have been introduced in the present edition."

The general introduction to this book reviews briefly the historic side of the nucleus idea, radio activity, constitution of the nuclei, and characteristic constants and units in nuclear physics. With this as a background the text proceeds into a description on methods that have been developed in order to detect and measure

the radiations emitted by radioactive substances. These are divided into two parts, viz.—methods in which the observed effect is due to so large a number of particles that fluctuations due to individual particles are smoothed out, and methods in which single elementary processes are observed. In the former, ionization chambers and photographic methods are referred to, and in the latter, scintillations, point and tube counters, and the Wilson cloud chamber are touched upon. While this particular part of the book is not very lengthy, it is illustrative of the remarkable descriptive powers exhibited throughout the book.

Following this the general laws of radioactive disintegration are treated on; then alpha, beta, and gamma radiations—their interaction with matter, and the ray spectra of the natural radioelements. The general properties of the nuclei and the theory of nuclear structure should prove especially interesting as well as the chapter on the artificial disintegration of the nuclei, in view of the very recent work accomplished along these lines and the belief that we may be on the threshold of untold discoveries. The last chapter of the book is devoted to cosmic rays wherein there is briefly outlined the work to date which has brought great progress in the knowledge of their properties, and further discussion is directed toward intensity and secondary effects of the rays.

In the back of the book there is a section devoted to interesting photographs reproduced in plates. Following this there is a bibliography on the subject emphasizing references since 1930.

An outstanding feature of this book is its clarity and conciseness in presentation. It is a well done survey of the present status of investigation of nuclear phenomena, stressing summaries rather than detailing extensive theoretical analysis.

R. H. OPPERMANN.

ANSCHAULICHE QUANTENTHEORIE EINE EINFÜHRUNG IN DIE MODERNE AUFFASSUNG DER QUANTENERSCHEINUNGEN, von Dr. Pascual Jordan. 320 pages, 16 × 24 cms. Berlin, Julius Springer, 1936. Price 12 marks.

The author of this paper-bound book undertook the presentation of the subject with the dominant thought that it is absolutely necessary to master the fundamentals in order to be in a position to absorb the more advanced knowledge. Anything other than a thorough assimilation of the fundamentals will eventually lead to a need for it. This is particularly true when seeking to understand a new theory, in that the old must first be understood well in order to grasp the elements of the new from certain of the old. The author stresses this transference.

The thought is brought into play in the very beginning of the book, for Chapter I is devoted to a description of the performance of fundamental experiments or those experiments which reveal the most essential facts for a knowledge of the quantum physics and the basis for the legality of the more simple mathematical formations. Together with this, that which is necessary to obtain the relationship of the classical and quantum physics is given. This chapter is limited to theories on thermodynamics and relativity. In Chapter II this is furthered in the treatment on the theoretical analysis of the experiments. The Bohr principle is discussed and through thought-stimulating passages the text is led onward.

Chapter III bridges from all of what has previously been treated upon to quantum and wave mechanics. Here the fundamentals are taken up with a description of the Matrix scheme and its simple uses, then the functions of wave

mechanics, and examples of uses given, which is followed by reference to the statistical transformation theory. The theory of two and more particles and the ideal gas begins Chapter IV and this is carried through relativity wave equations and the quantum theory of electromagnetic fields etc. The fifth and last chapter is devoted to the atom and a discussion on the construction of the world.

The book is a complete description of the theory and at the same time it is written so that no room is left for careless generalizations which may lead to misconceptions.

R. H. OPPERMANN.

PROPERTIES OF MATTER, by F. C. Champion, M.A., Ph.D., and N. Davy, M.Sc. 296 pages, diagrams, 15 × 22.5 cms. New York, Prentice-Hall, Inc., 1937. Price $4.50.

As time passes by and man gathers more and more knowledge of the laws of nature it becomes necessary to pause and often re-define the names and classes of certain studies. This is because the subjects followed seldom stay confined to narrow channels, rigidly avoiding the borders of the channels of other subjects. A notable example of this is the study of General Physics and Physical Chemistry. In this respect the authors of the book at hand state in the Preface, "It is now impossible to draw a dividing line between General Physics and Physical Chemistry in some topics. A concise account of Debye and Huckel's theory of strong electrolytes has therefore been given, and a whole chapter has been devoted to the new and important subject of Surface Films."

The book does not treat on the entire subject of the Properties of Matter. Only certain parts of it are covered. They include acceleration due to gravity, the Newtonian constant of gravitation, elasticity, compressibility of solids and liquids, seismic waves of which the geophysical problems refer to the longitudinal and transverse waves, capillarity, kinetic theory, osmotic pressure, diffusion, viscosity, and errors of measurement including methods of determining Planck's Constant.

The text is intended for the advanced student, one who has had grounding in prerequisite topics such as central orbits, gyroscopic motion, kinematics and dynamics. The construction of the book is such that the student is carried through examples of principles previously treated upon. In other words principles are first stated, then an example follows in which there is illustration made of every step. Exercises for each chapter's coverage are given in the back of the book which is followed by a list of answers and hints for the solution of the exercises. The latter is somewhat unusual. It may provide considerable assistance in the way of impressing certain important points on the student's mind.

For those to whom the book is intended, it should prove to be valuable not only as a text but as a reference work as well.

R. H. OPPERMANN.

ANALYTIC GEOMETRY AND CALCULUS, by Bolling H. Crenshaw, M.E., and Cincinnatus D. Killebrew, M.S. Second edition, revised by Ralph D. Doner. 222 pages, illustrations, tables, 16 × 24 cms. Philadelphia, P. Blakiston's Son & Co., Inc. 1937. Price $2.75.

This text was prepared to give the students at the Alabama Polytechnic Institute a working knowledge of engineering mathematics. Beginning with a

review of algebra and trigonometry, there is devoted some fifty pages to analytical geometry and, following this, some one hundred thirty pages to the calculus, differential then integral. There is contained all that is usually given in a college course in plane analytic geometry, with the omission of all reference to poles and polars and the discussion of the general equation of the second degree containing the xy term. The differential calculus is introduced before the discussion of tangents and normals in order that its easier and more general methods may be applied to this discussion. The differentiation of transcendental functions is taken along with the differentiation of algebraic functions. Formal integration is thoroughly discussed before taking up the definite integral and its applications. A chapter on Series is at the end of the book.

The plan and method of treatment are such that results in a presentation in as simple manner as possible. Much care has been taken in selecting only the necessary material for the text and every resort is taken advantage of in obtaining helpful assistance for the student.

R. H. OPPERMANN.

THE STORY OF HUMAN ERROR, edited by Joseph Jastrow. 444 pages, 15.5 × 23.5 cms. New York and London, D. Appleton-Century Company, Inc., 1936. Price $3.50.

In 1883 William Graham Sumner of Yale University said that one of the most subtle and widespread social fallacies consisted "in the impression made on the mind for the time being by a particular fact, or by the interests of a particular group of persons, to which attention is directed while other facts or the interests of other persons are entirely left out of account." How true this is with particular reference to the history of science. Why have we not reached our present state of scientific development before now? Our history of science seldom if ever records pivotal errors that were followed by long stagnant periods.

The Story of Human Error is a book that traces false leads in the development of the various branches of science. It is a book to which twelve recognized specialists have contributed, each on a different scientific subject, each pointing out the great error in his respective field.

The reader is introduced to the subject by a section entitled "The Procession of Ideas" by Joseph Jastrow. Here, the author makes mention that the story of the triumphs of man the thinker should not crowd out the yet more instructive career of man the blunderer. He traces the history of error generally, back to the earliest stages of thought and shows that the study of error as we know it today was attempted as long ago as Roger Bacon, who called misleading tendencies impediments of thought. Using thought as a basis, he travels through the topics of logical procedures, explanations, generalizations, applications, deductions, logic, etc.

After this, the book is divided into two parts. The first covers the cosmic, the physical and the living realm. Under the cosmic realm are treated error in astronomy by Harlan T. Stetson, error in geology by Kirtley F. Mather, and error in geography by John Leighly. In the physical realm and writing on error in physics is W. F. G. Swann, Director of the Bartol Research Foundation of The Franklin Institute. The subject of mathematics is covered by E. T. Bell and that on chemistry by C. A. Browne. Under the living realm, the subjects of zoology, physiology and neurophysiology are taken up, each by a specialist.

The introduction to the second part of the book is by James Harvey Robinson on the topic of the "Process of Civilization." This part is further divided into the human realm and the applied realm. Subjects such as anthropology, psychology, sociology, medicine, and psychiatry are covered, likewise each by a specialist.

The book on this very unusual subject is written on the highest plane of historical interest, scientific accuracy and literary skill. It is a notable contribution that is interesting, and very informative.

R. H. OPPERMANN.

ELEKTRONENTHEORIE DER METALLE, von Dr. Herbert Fröhlich. 386 pages, illustrations, 14.5 × 22 cms. Berlin, Julius Springer, 1936. Price 27 marks.

This is an up-to-date treatment of an up-to-date subject. It presents in a well planned manner the broader viewpoint from an introductory angle and is characteristic of the modern text in that it leads up to the conclusion of each of its topics from simple fundamentals, including everything that is necessary for a clear understanding.

The treatment begins with a general survey of the development of the electron theory of metals which is followed by the text proper. First the more obvious and apparent aspects are taken up such as the conception of the electron with respect to constant potential and varying potential, then simple problems explaining the process of emission, photoelectric effects etc. are given weight. The thermoelectric and magnetic effect are included. Next the imperfect conductor is discussed and this is followed by a descriptive illustration of the construction of the model of the metal atom in the light of the general subject. The last chapter of the book is devoted to a systematic discussion on elements with and without compact inner shells, bismuth, and liquid metals.

The author has alluded to experimental physics, in this work, which, together with the knowledge of the physics of metals, provides a safe means of extracting the theory. The treatment necessarily leans on the use of mathematics to a considerable extent.

The outstanding feature of this text is thoroughness from the beginning to end, and the work can be recommended to those who are prepared for and desire such a treatment.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 570. The Effect of Lateral Controls in Producing Motion of an Airplane as Computed from Wind-Tunnel Data, by Fred E. Weich and Robert T. Jones. 26 pages, illustrations, tables, 23.5 × 29 cms. Washington, Government Printing Office, 1936. Price ten cents.

An analytical study of the lateral controllability of an airplane has been made in which both the static rolling and yawing moments supplied by the controls and the reactions due to the inherent stability of the airplane have been taken into account. The investigation was undertaken partly for the purpose of coordinating the results of a long series of wind-tunnel investigations with phenomena observed in flight tests; for this reason a hypothetical average airplane, embodying the essential characteristics of both the wind-tunnel models and the full-size test airplanes, was assumed for the study.

Stability derivatives for the average airplane and for several of the actual

flight-test airplanes were computed, and computations were made in an attempt to reproduce by the theory the conditions of several actual flight tests. Computations made of forced rolling and yawing motions of an F-22 airplane caused by a sudden deflection of the ailerons were found to agree well with actual measurements of these motions.

The conditions following instantaneous full deflections of the lateral control have been studied, and some attention has been devoted to the controlling of complete turn maneuvers. A portion of the work was devoted to a study of controllability at stalling angles, and the results of this application of theory were found to agree qualitatively with flight-testing experience.

Report No. 577, Prechamber Compression-Ignition Engine Performance, by Charles S. Moore and John H. Collins, Jr. 20 pages, illustrations, tables, 23.5 × 29 cms. Washington, Government Printing Office, 1937. Price ten cents.

Single-cylinder compression-ignition engine tests were made to investigate the performance characteristics of the prechamber type of cylinder head. Certain fundamental variables influencing engine performance—clearance distribution, size, shape, and direction of the passage connecting the cylinder and prechamber, shape of prechamber, cylinder clearance, compression ratio, and boosting—were independently tested. Results of motoring and of power tests, including several typical indicator cards, are presented.

Results of the investigation indicate that for maximum performance of this 5- by 7-inch engine at speeds up to 1,500 r.p.m., the compression ratio should be between 15.5 and 17.5 and the prechamber should be as large as possible, disk-shaped, and connected to the cylinder by a single passage. A strong rotational air flow should be created in the prechamber by introducing the passage tangentially. Flaring should be employed on the cylinder end of the passage to spread the issuing gases over the flat piston crown. At 1,500 r.p.m., the injection system should deliver in approximately 20 crank-shaft degrees the full-load fuel in the shape of a narrow conical spray with high penetration. This spray should be directed across the disk chamber toward the mouth of the connecting passage. Boosting the inlet-air pressure effectively raises the power output. As the prechamber is inaccessible for scavenging and the lack of clearance under the valves prohibits the use of proper valve timing, the prechamber type of cylinder head is judged to be incapable of developing the high specific output required of aircraft engines.

Report No. 583, The Rolling Friction of Several Airplane Wheels and Tires and the Effect of Rolling Friction on Take-Off, by J. W. Wetmore. 8 pages, illustrations, tables, 23.5 × 29 cms. Washington, Government Printing Office, 1937. Price ten cents.

Tests were made to determine the rolling friction of airplane wheels and tires under various conditions of wheel loading, tire inflation pressure, and ground surface. The effect of wheel-bearing type was also investigated. Six pairs of wheels and tires were tested including two sizes of each of the types designated as standard (high pressure), low pressure, and extra low pressure. The results of calculations intended to show the effect of variations in rolling friction on take-off are also presented.

The values of rolling-friction coefficient obtained on a concrete runway varied from 0.009 to 0.035; on firm turf, from 0.023 to 0.054; and on moderately soft turf, where only the high-pressure tires were tested, from 0.064 to 0.077. Of the variables investigated, the ground-surface condition was the most important in its effect on the rolling-friction coefficient. For comparable conditions, both on a concrete surface and on firm turf, the standard wheels and tires offered the least resistance to rolling. Slightly higher values were obtained with the low-pressure wheels and tires, and the extra low-pressure type gave the highest values. The variation in rolling-friction coefficient with wheel loading and inflation pressure was generally quite small. The value of rolling-friction coefficient for wheels equipped with plain bearings was appreciably greater than that for the same wheels provided with roller bearings. The effect on take-off of all the variables, with the exception of ground-surface condition, was sufficiently small to be neglected in rough calculations of take-off performance but should be considered in more accurate work.

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Dielectric Phenomena in High Voltage Cables, by D. M. Robinson, with a foreword by P. V. Hunter. 173 pages, illustrations, tables, 14 × 22 cms. Pittsburgh, Instruments Publishing Co., 1936.

The Handmaiden of the Sciences, by Eric Temple Bell. 216 pages, illustrations, 14.5 × 22.5 cms. Baltimore, The Williams & Wilkins Company, 1937. Price $2.00.

Distillation, by Joseph Reilly, with foreword by Prof. Sydney Young. 118 pages, illustrations, 11 × 17.5 cms. London, Methuen & Co., Ltd. Price $1.25.

Cugle's Examination Guide for Lifeboat Men and Seamen, by Charles H. Cugle. 188 pages, illustrations, tables, 14 × 20 cms. New York, E. P. Dutton & Co., 1937. Price $1.50.

The Identity Theory, by Blamey Stevens, 2nd edition. 258 pages, 14.5 × 22 cms. Manchester, Sherratt & Hughes. New York, G. E. Stechert & Co., 1936. Price 7s. 6d.

Canada Department of Mines and Resources. Fuel Briquetting, by R. A. Strong, E. Swartzman and E. J. Burrough. 100 pages, plates, tables, 16.5 × 25 cms. Ottawa, King's Printer, 1937. Price 25 cents.

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National Advisory Committee for Aeronautics. Technical Notes: No. 592, A Study of the Factors Affecting the Range of Airplanes, by David Biermann, 43 pages, figures. No. 593, Pressure Drop in Tubing in Aircraft Instrument Installations, by W. A. Wildhack, 26 pages, tables, figures. No. 594, Tank Tests of Two Models of Flying-Boat Hulls to Determine the Effect of Ventilating the Step, by John R. Dawson, 8 pages, figures. 3 pamphlets, 20 × 26 cms. Washington, Committee, 1937.